abc
Basic Connections

Alberto Piganti

ABC Basic Connections 2018.indd 1 23/11/2017 18:01

ABC: Basic Connections
by Alberto Piganti

Printed in Spain by Artes Graficas Mawijo, S.A.

Published by Alberto Piganti - ESY3370544T
C/ Perú 4 planta 1 oficina 2
28290 Las Rozas, Madrid (Spain)

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Printing History:
November 2017: First Edition

ISBN: 978-84-946930-0-7

abc

Basic Connections

Important Message:

Your safety is your own responsibility, including proper use of equipment and safety gear, and determining whether you have adequate skill and experience to complete a specific project. In order to show the project steps more clearly, some illustrations do not depict safety precautions or equipment. Electricity and other resources are dangerous unless used properly and with adequate precautions, including safety gear. The projects included in this book are not intended for use by unsupervised children.

Use the instructions and suggestions in ABC: Basic Connections at your own risk. PighiXXX and the author disclaim all responsibility for any resulting damage, injury, or expense.

Dedicated to the people who have always believed in me:
My wife Olga and my mother

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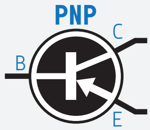
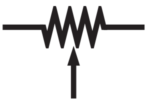
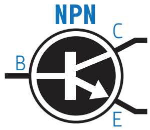


PNP Transistor

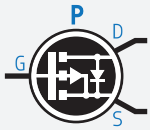


Trimmer or Potentiometer



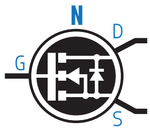
NPN Transistor

Ceramic Capacitor



P-Channel MOSFET

Electrolytic Capacitor



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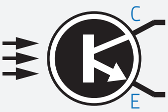
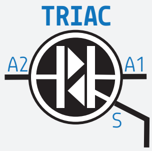


Phototransistor



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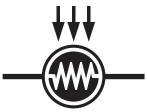
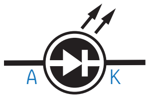


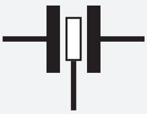
Photoresistor (LDR)

NTC Thermistor

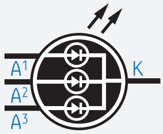
Crystal



LED

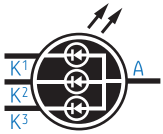


Resonator



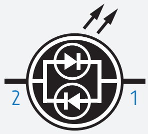
Common Cathode RGB LED

Silicon Diode



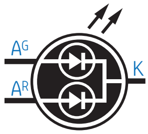
Common Anode RGB LED

Zener Diode

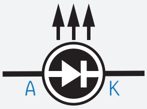


Bi-Color LED

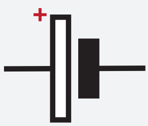
Schottky Diode



Bi-Color LED



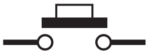
IR Emitter



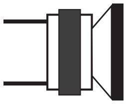
Battery

IR Detector

Fuse

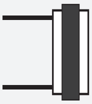


Pushbutton

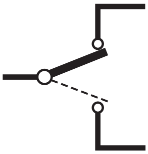


Buzzer

Switch (SPST)

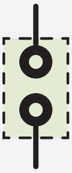


Piezo
Buzzer

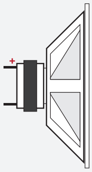


Switch (SPDT)

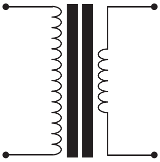
Piezo
Element



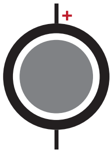
Jumper



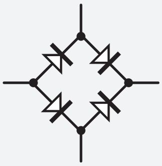
Speaker



Transformer

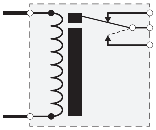


Microphone

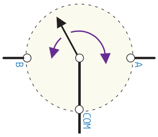


Bridge
Rectifier

Device



Relay



Encoder

Supply	Crossing
Ground	Connection
IN/OUT	Junction

Online Content

You can download additional information, support files and code related each schematic from the URLs on the cloud icons.

0-1.es/xx

We have a web page for this book where we list errata, examples, and any additional information:

abcthebook.com

For technical questions about this book, please contact our support team at:

contact@abcthebook.com

Conventions

This book uses American English spelling and the decimal point as the decimal mark. Although the International System of Units prescribes inserting a space between a number and a unit of measurement, such spaces are omitted in this book for aesthetic reasons.

The following conventions are used in this book:

Standard Input/Output Signal

PWM Input/Output Signal

Interrupt Pin

Analog Input/Output Signal

Information
Useful tips about the circuit

Caution
Useful tips about common pitfalls and limitations of the circuit

Stop
Useful advice to help you avoid destroying any component

Information
Useful information about the circuit

SEN — Device Pin Name
Used also in pinout diagrams

SDA — Pin Name

Acknowledgments

I am most grateful to a great number of reviewers for their constructive criticism and suggestions. I am also indebted to the many authors whose books or websites I have consulted over the years.

This book has been realized by the effort and skill of many people.

I thank Raffaele Piacente (AKA Testato) for his excellent proofreading and testing work.

Thanks to Adafruit and Limor Fried for her support since the earliest days and for believing in my work.

On behalf of everyone who has downloaded user-contributed Arduino™ libraries, I would like to thank the authors who have generously shared their knowledge.

A big thanks to the entire Arduino™ co unity and to and all my supporters that encourage me daily to create new content. Thanks to my friend Luis Estrella who has always believed in me and helped me in this publishing venture. And last, but not least, thanks to my wife Olga for her patience in the face of deadline-induced irritability.

And above all, thanks to all of you who supported us on our crowdfunding campaign. Thank you for making it possible!

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A1

Ohm's Law

Basic Concepts

Ohm's law is one of the most fundamental relationships found in electric circuits: for a given resistance, current is directly proportional to voltage. In other words, if the voltage through a circuit with a fixed resistance increases, the current increases. If the voltage decreases, the current decreases as well. Ohm's law is expressed with a simple mathematical formula:

$$V = I \times R$$

Where **V** stands for voltage (in volts), **I** stands for current (in amperes), and **R** stands for resistance (in ohms). Ohm's law is very useful because it lets you calculate an unknown voltage, current, or resistance. If you know two of these three quantities you can calculate the third.

Known values	Resistance (R)	Current (I)	Voltage (V)	Power (P)
Current & Resistance			**$V=I \times R$**	**$P=I^2 \times R$**
Voltage & Current	**$R=V/I$**			**$P=V \times I$**
Power & Current	**$R=P/I^2$**		**$V=P/I$**	
Voltage & Resistance		**$I=V/R$**		**$P=V^2/R$**
Power & Resistance		**$I=\sqrt{P/R}$**	**$V=\sqrt{P \times R}$**	
Voltage & Power	**$R=V^2/P$**	**$I=P/V$**		

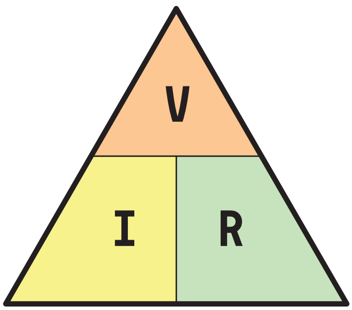
A1

0-1.es/A1

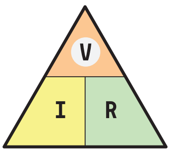
Ohm's Law

Basic Concepts

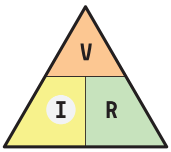
It is easier to remember this Ohm's law relationship by using pictures. Here the three quantities of **V**, **I** and **R** have been superimposed onto a triangle (called the Ohm's Law Triangle). This arrangement represents the position of each quantity within the Ohm's law formulas, making it easier to remember.



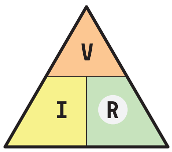
Transposing the standard Ohm's Law equation above will give us the following combinations of the same equation:



$$V = I \times R$$



$$I = \frac{V}{R}$$



$$R = \frac{V}{I}$$

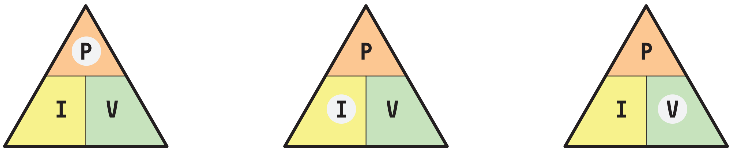
0-1.es/A1

A1

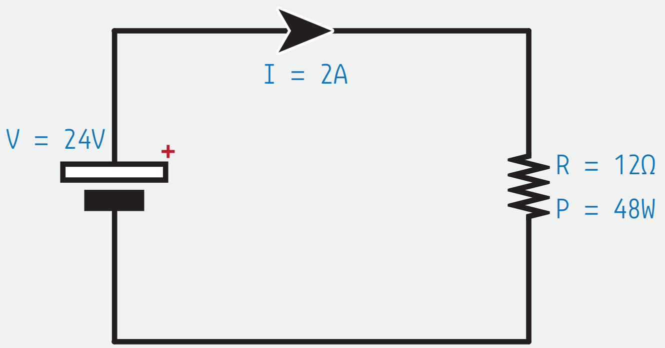
Ohm's Law

Basic Concepts

Electric Power (**P**) is the rate at which energy is absorbed or produced within a circuit. Electric power is measured in watts (**W**), that is, joules per second. A source of energy will supply power while the connected load absorbs it. A light bulb, for instance, would absorb power and convert it into both heat and light. The higher its value or rating in watts, the more electrical power it is likely to demand.



$$P = I \times V \qquad I = \frac{P}{V} \qquad V = \frac{P}{I}$$



Example test circuit

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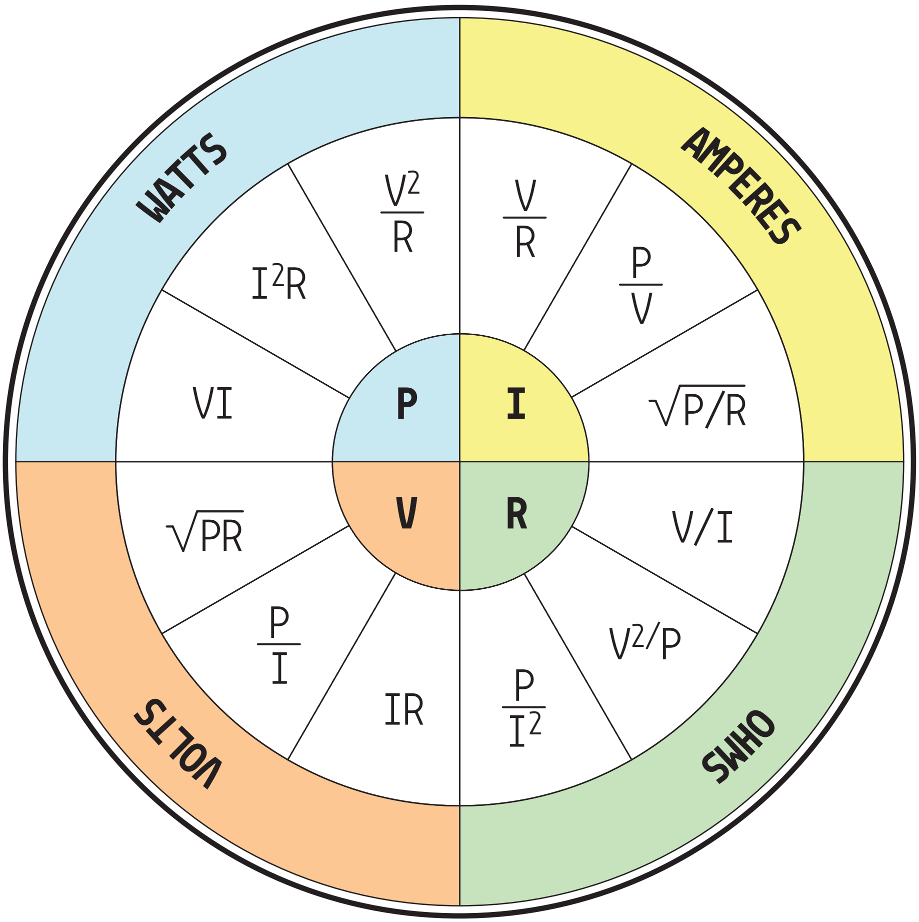
Ohm's Law

Pie Chart Reference



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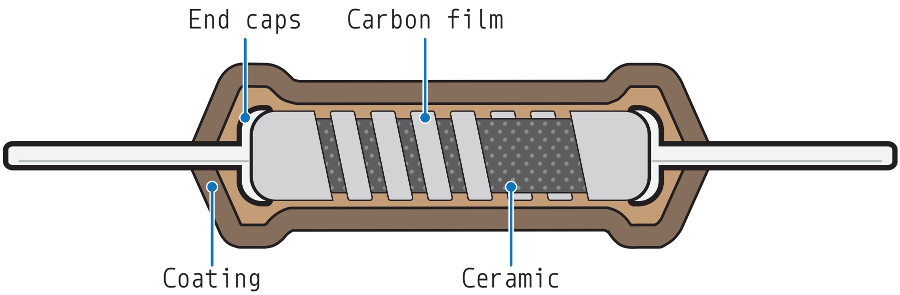
A2

Resistors

Basic Concepts

Conductors are a materials that allow current to flow through them and insulators are materials that don't. The key factor that determines whether a material is a conductor or an insulator is how easily its atoms give up electrons to move charge along. Most atoms are very attached to their outermost electrons, and are therefore good insulators. But some atoms don't, making them good conductors.



If a conductor and an insulator are mixed together, the resulting material would not conduct current very well. Such a material would have an inherent resistance, resisting the flow of current through it. The degree to which the material resists current flow depends on its exact mixure of elements. A conducting material such as carbon might be mixed with an insulating material such as ceramic. If the mix is mostly carbon, the resistance of the mixture will be low. Whereas if the mix is mostly ceramic, its resistance will be high.

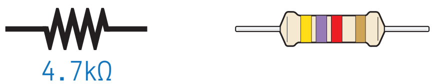
A2

0-1.es/A2

Resistors

Basic Concepts

Resistance is measured in ohms, represented by the Greek letter omega (**Ω**). The ohm is defined as the amount of resistance required to allow one ampere of current to flow when one volt of potential is applied to the circuit. In other words, if you connect a 1-ohm resistor across the terminals of a 1-volt battery, one amp of current will flow through the resistor.



In schematic diagrams, resistors are represented by a jagged line, with its resistance value typically written next to the resistor symbol.

The abbreviations k (for kilo) and M (for mega) are used for thousands and millions of ohms. Thus, a 1,000 ohm resistance is written as 1 kΩ, and a 1,000,000 ohm resistance is written as 1 MΩ.

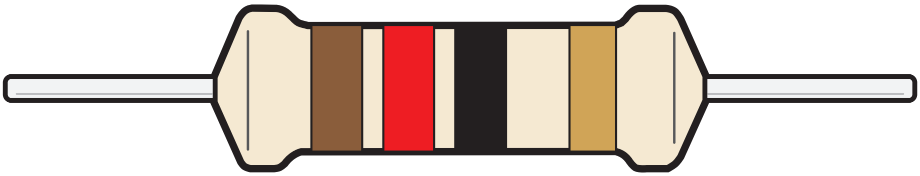
The resistance value of a resistor can be determined by examining the color codes that are painted as stripes on its outer surface. These stripes indicate its resistance value in ohms and its tolerance, which indicates the maximum variation of the real resistance value compared to the value represented by the stripes.

0-1.es/R1

R1

E24 Resistors

Color Code



	1ST Digit	2ND Digit	Multiplier	Tolerance
Black	0	0	x1	
Brown	1	1	x10	
Red	2	2	x100	
Orange	3	3	x1k	
Yellow	4	4	x10k	
Green	5	5	x100k	
Blue	6	6	x1M	
Violet	7	7		
Gray	8	8		
White	9	9		
Gold			x0.1	±5%
Silver				±10%

R1

0-1.es/R1

E24 Resistors

Common Standard Values

1Ω	10Ω	100Ω	1kΩ	10kΩ	100kΩ	1MΩ
1.2Ω	12Ω	120Ω	1.2kΩ	12kΩ	120kΩ	1.2MΩ
1.5Ω	15Ω	150Ω	1.5kΩ	15kΩ	150kΩ	1.5MΩ
1.8Ω	18Ω	180Ω	1.8kΩ	18kΩ	180kΩ	1.8MΩ
2.2Ω	22Ω	220Ω	2.2kΩ	22kΩ	220kΩ	2.2MΩ
2.7Ω	27Ω	270Ω	2.7kΩ	27kΩ	270kΩ	2.7MΩ
3.3Ω	33Ω	330Ω	3.3kΩ	33kΩ	330kΩ	3.3MΩ
3.9Ω	39Ω	390Ω	3.9kΩ	39kΩ	390kΩ	3.9MΩ
4.7Ω	47Ω	470Ω	4.7kΩ	47kΩ	470kΩ	4.7MΩ
5.6Ω	56Ω	560Ω	5.6kΩ	56kΩ	560kΩ	5.6MΩ
6.8Ω	68Ω	680Ω	6.8kΩ	68kΩ	680kΩ	6.8MΩ
8.2Ω	82Ω	820Ω	8.2kΩ	82kΩ	820kΩ	8.2MΩ

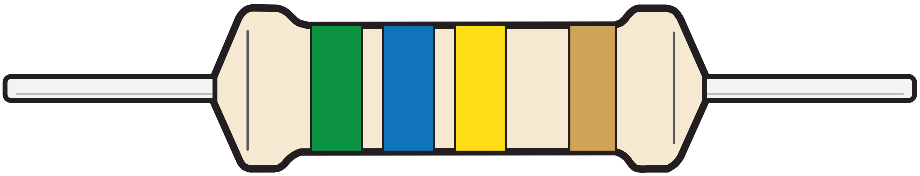
Partial list, full version available online

0-1.es/R2

R2

E48 Resistors

Color Code



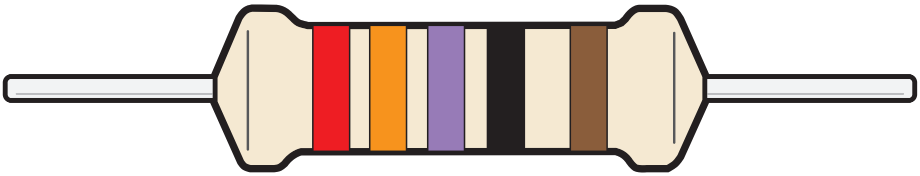
	1st Digit	2nd Digit	Multiplier	Tolerance
Black	0	0	x1	
Brown	1	1	x10	
Red	2	2	x100	±2%
Orange	3	3	x1k	
Yellow	4	4	x10k	
Green	5	5	x100k	
Blue	6	6	x1M	
Violet	7	7		
Gray	8	8		
White	9	9		
Gold			x0.1	±5%
Silver			x0.01	±10%

R3

0-1.es/R3

E96/E192 Resistors

Color Code



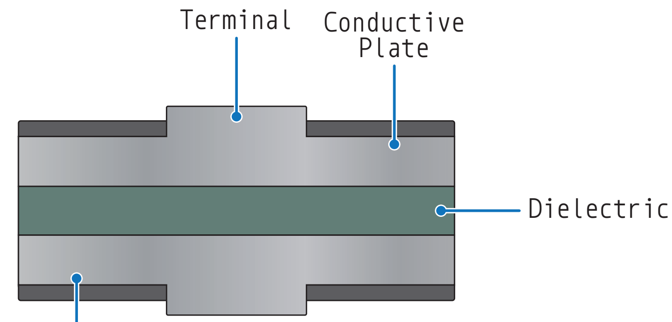
	1st Digit	2nd Digit	3rd Digit	Multiplier	Tolerance
Black	0	0	0	x1	
Brown	1	1	1	x10	±1%
Red	2	2	2	x100	±2%
Orange	3	3	3	x1k	
Yellow	4	4	4	x10k	
Green	5	5	5	x100k	±0.5%
Blue	6	6	6	x1M	±0.25%
Violet	7	7	7	x10M	±0.10%
Gray	8	8	8		
White	9	9	9		
Gold				x0.1	±5%
Silver				x0.01	±10%

A3

Capacitors

Basic Concepts

Capacitors are components that that store electric energy as an electric field. They consist of two plates made of a conducting material such as silver or aluminum, separated by a thin insulating material such as Mylar or ceramic. The two conducting plates are connected to terminals so that a voltage can be applied across them.



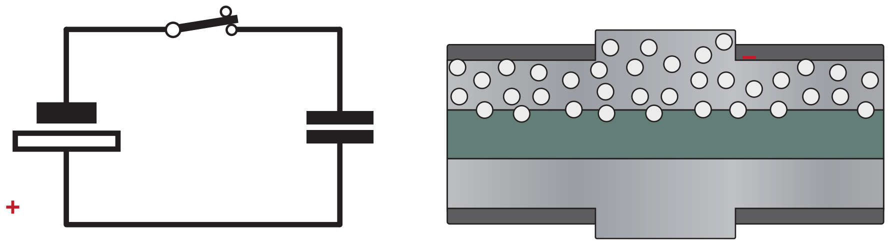
Capacitor

Because the two plates are separated by a dielectric, that is, an electrical insulator that can be polarized by an electric field, a closed circuit is not formed. Nevertheless, current flows for an instant. When the voltage from a source such as a battery is connected, the negative terminal of the battery immediately begins to push electrons toward one of the plates.

Capacitors

Basic Concepts

At the same time, the positive side of the battery voltage begins to pull electrons (negative charges) away from the second plate. The electric field that builds up between the two plates allows current to flow. As the plate on the negative side of the circuit fills with electrons, the electric field created by them push the electrons away from the plate on the other side of the dielectric, toward the positive side of the battery voltage.



Capacitor Charging

As current flows, the negative plate of the capacitor builds up an excess of electrons, whereas the positive side develops a corresponding deficiency of electrons. At the same time, the voltage between the two plates increases proportionally to the difference in charge between the two plates.

The voltage continues to increase until the capacitor voltage equals the battery voltage. Once they are the same, current stops flowing through the circuit, and the capacitor is said to be charged.

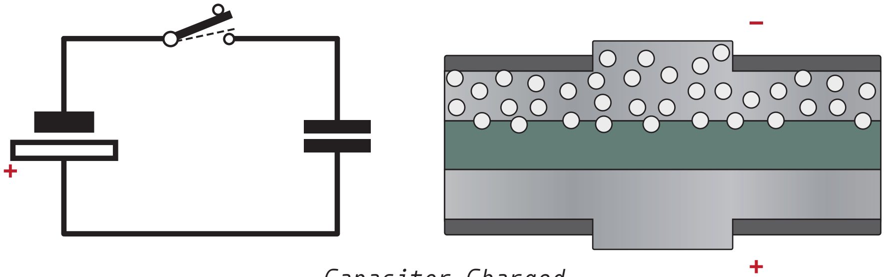
0-1.es/A3

A3

Capacitors

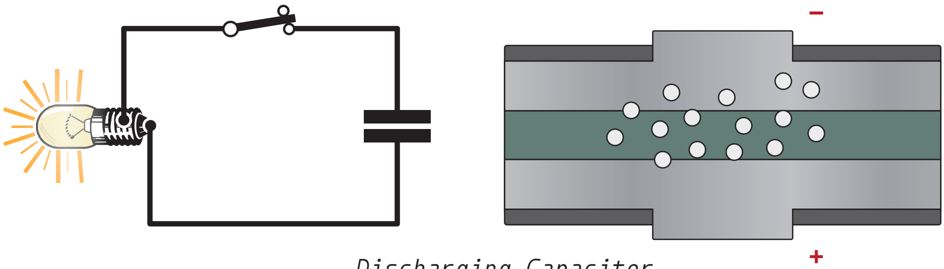
Basic Concepts

Once the capacitor has been charged it will acquire the same voltage as the battery, and the charge will remain in the capacitor even when disconnected. The amount of charge capacitors can store is proportional to the area of their plates.



Capacitor Charged

When a charged capacitor is connected to a circuit, the voltage across its plates will drive current through the circuit, discharging the capacitor.



Discharging Capacitor

A3

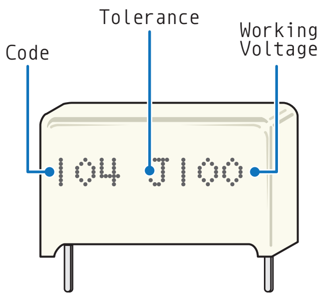
0-1.es/A3

Capacitors

Basic Concepts

Capacitance is the electrical property of a capacitor that defines its ability to store an electric charge onto its two plates, with the unit of capacitance being the farad (**F**). A 1-farad capacitor can store 1 coulomb of charge at 1 volt. A coulomb is 6.25e18 (6.25 billion billion) electrons. Based on this definition, one ampere represents a rate of electron flow of 1 coulomb of electrons per second.

As in the case of resistors, capacitors also have a manufacturing tolerance for their capacitance value.



If there is enough room on the package, most manufacturers print the capacitance value directly on the capacitor along with other information such as the voltage rating and the tolerance.

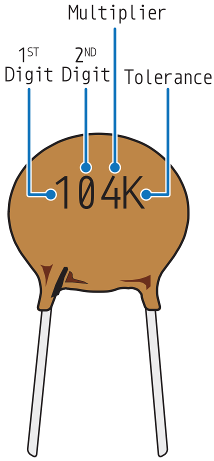
0-1.es/R4

R4

Capacitors

Markings

Multiplier	Multiply by
0	1
1	10
2	100
3	1,000
4	10,000
5	100,000
8	0,01
9	0,1



10×10,000 = 100,000pF
100,000pF = **0.1µF ±10%**

Letter	Tolerance >10pF	Tolerance <10pF
B		±0.1pF
C		±0.25pF
D		±0.5pF
F	±1%	±1pF
G	±2%	±2pF
H	±3%	
J	±5%	
K	±10%	
M	±20%	

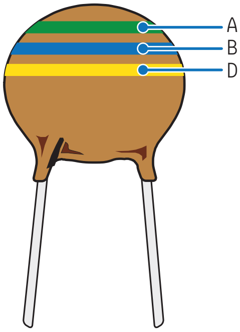
Conversion Table

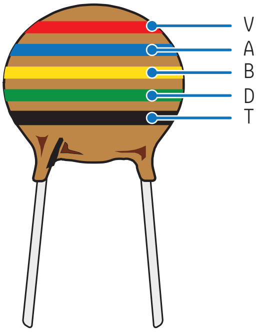
picofarads pF	nanofarads nF	microfarads µF
1	0.001	0.000001
10	0.01	0.00001
100	0.1	0.0001
1,000	1	0.001
10,000	10	0.01
100,000	100	0.1
1,000,000	1,000	1
10,000,000	10,000	10
100,000,000	100,000	100

R5

0-1.es/R5

Capacitors
Color Code





Type	Capacitor Type
J	**Dipped tantalum**
K	**Mica**
L	**Polyester**
M	**Electrolytic, 4-band**
N	**Electrolytic, 3-band**

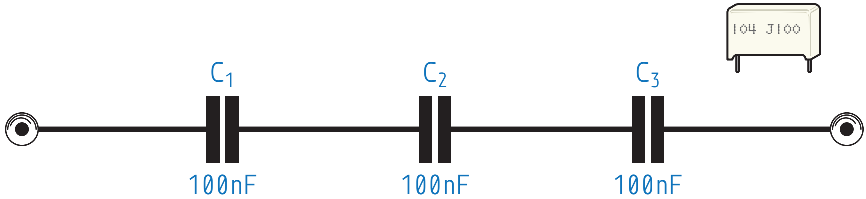
	A	**B**	**D**	**T**		**V**				
	Digit A	Digit B	Multiplier	Tolerance >10pF	Tolerance <10pF	Voltage Rating J	K	L	M	N
Black	0	0	x1	±20%	±2pF	4	100		10	10
Brown	1	1	x10	±1%	±0.1pF	6	200	100	1.6	
Red	2	2	x100	±2%	±0.25pF	10	300	250	4	35
Orange	3	3	x1k	±3%		15	400		40	
Yellow	4	4	x10k	±4%		20	500	400	6.3	6
Green	5	5	x100k	±5%	±0.5pF	25	600		16	15
Blue	6	6	x1M			35	700	630		20
Violet	7	7				50	800			
Gray	8	8	x0.01	+80% −20%			900		25	25
White	9	9	x0.1	±10%	±1pF	3	1000		2.5	3
Gold			x0.1	±5%			2000			
Silver			x0.01	±10%						

0-1.es/A4

A4

Components in Series

Capacitors

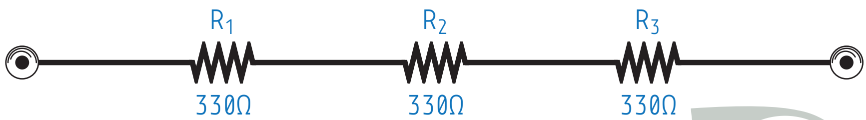


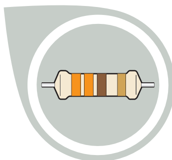
$$C_{TOTAL} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

$$C_{TOTAL} = \frac{1}{\frac{1}{100} + \frac{1}{100} + \frac{1}{100}}$$

$$C_{TOTAL} = \mathbf{33.33nF}$$

Resistors





$$R_{TOTAL} = R_1 + R_2 + R_3$$

$$R_{TOTAL} = 330+330+330$$

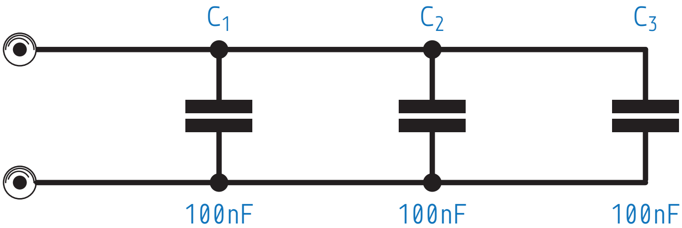
$$R_{TOTAL} = \mathbf{990\Omega}$$

A5

0-1.es/A5

Components in Parallel

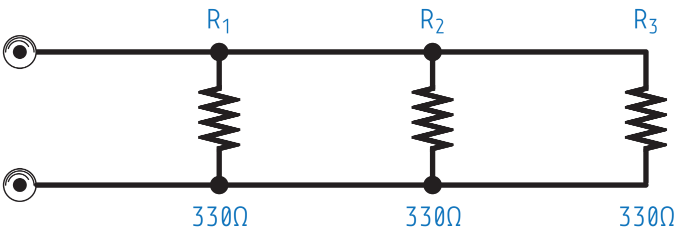
Capacitors

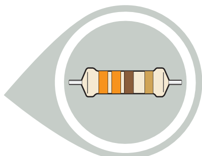


$$C_{TOTAL} = C_1 + C_2 + C_3 \qquad C_{TOTAL} = 100+100+100$$

$$C_{TOTAL} = \mathbf{300nF}$$

Resistors





$$R_{TOTAL} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \qquad R_{TOTAL} = \frac{1}{\frac{1}{330} + \frac{1}{330} + \frac{1}{330}}$$

$$R_{TOTAL} = \mathbf{110\Omega}$$

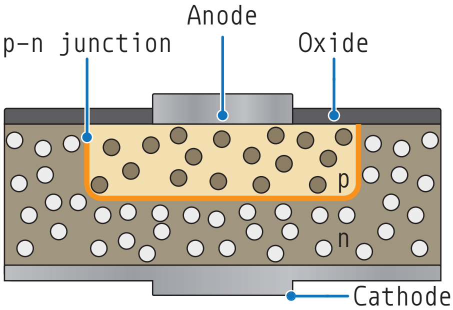
0-1.es/A6

A6

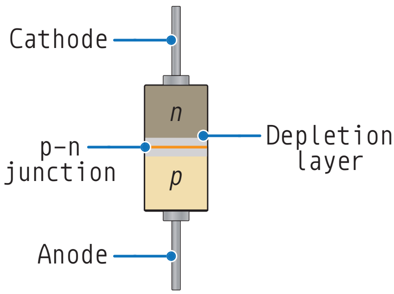
Diodes

Basic Concepts

Diodes are components made from a combination of a p-type and n-type semiconductor material, most commonly silicon.



Silicon Planar Diode Structure



The lead attached to the n-type semiconductor is called the cathode. Thus, the cathode is the negative side of the diode. Alternatively, the positive side of the diode, that is, the lead attached to the p-type semiconductor, is called the anode.

In the schematic symbol of the diode, the anode is represented as a triangle and the cathode is represented as a bar. You can think of the anode side of the symbol as an arrow that indicates the direction of conventional current flow, from positive to negative.

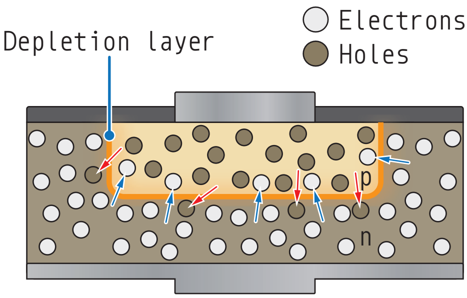
A6

0-1.es/A6

Diodes

Basic Concepts

When p-type and n-type silicon are placed together during the manufacturing process, a junction called p-n junction is created where the p-type and n-type materials meet. Holes, or lack of electrons, close to the junction in the p-type silicon are attracted into negatively charged n-type material at the other side of the junction.



Diode
Depletion layer

At the same time, electrons close to the junction in the n-type silicon are attracted to the positively charged p-type silicon. The recombination of holes and electrons produces a narrow region at the junction called the depletion layer.

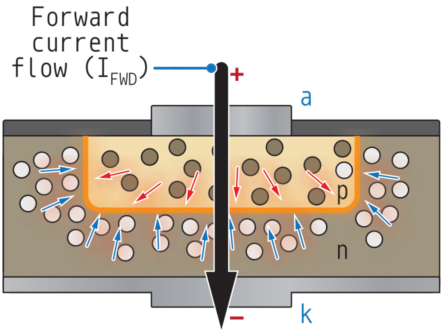
0-1.es/A6

A6

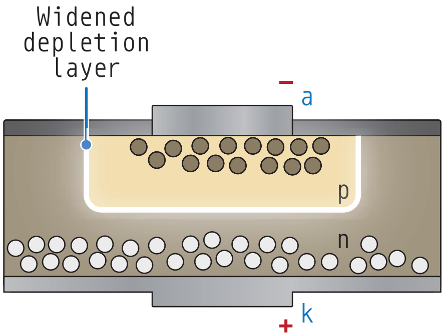
Diodes

Basic Concepts

When a voltage source is connected to a diode such that the positive side of the voltage source is on the anode and the negative side is on the cathode, the diode becomes conductive and allows current to flow. This configuration is called forward bias.



Diode in Forward Conduction



Reverse-Biased Diode

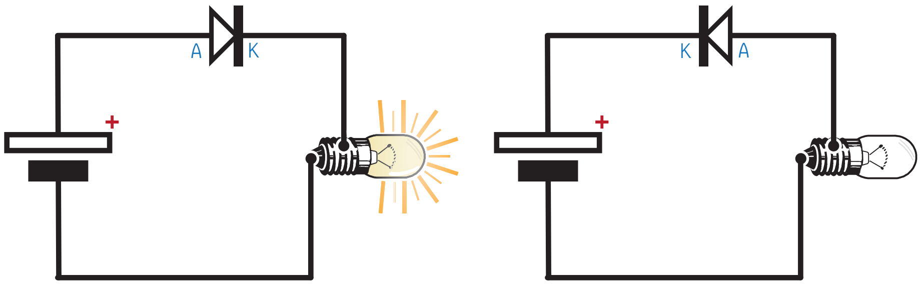
If the direction of the voltage is reversed, when connecting the positive side to the cathode and the negative side to the anode, current doesn not flow. In this case, the diode becomes an insulator. This configuration is called reverse bias.

0-1.es/A6

Diodes

Basic Concepts

Forward and reverse bias can be illustrated by connecting a light bulb to a battery with a diode in series. In the circuit on the left, the diode is forward biased, so current flows through the circuit and the light bulb lights up. In the circuit on the right, the diode is reverse biased, so current does not flow and the light bulb remains off.



Forward bias *Reverse bias*

When a diode is connected to a circuit, no current can flow between anode and cathode until the anode is made more positive than the cathode by a forward voltage sufficiently high to overcome the natural reverse potential of the p-n junction. This voltage, called forward voltage drop (V_F), is usually around 0.5V.

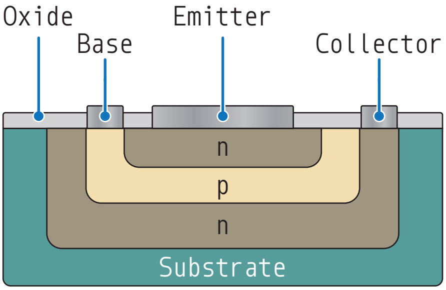
0-1.es/A7

A7

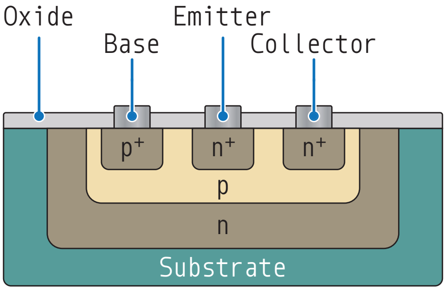
Transistors

Basic Concepts

Transistors similar to diodes but containing a third layer of either n-type or p-type semiconductor on one end. The interface between each of the three regions forms a p-n junction.



Planar transistor structure



Lateral planar transistor structure

One way in which transistors are made is by sandwitching a a p-type semiconductor between two n-type semiconductors. This type of transistors are called NPN because they have three regions: n-type, p-type, and n-type.

Alternatively, PNP transistors are made by sandwitching an n-type semiconductor between two p-type semiconductors.

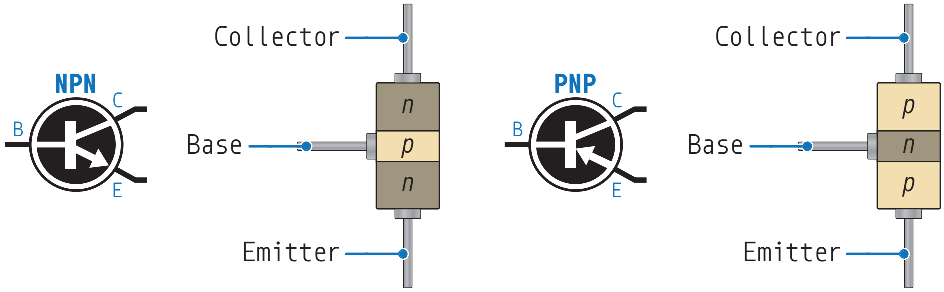
A7

0-1.es/A7

Transistors

Basic Concepts

Each of the three regions of semiconductor material in a transistor has a lead attached to it. They are called collector, base and emitter respectivelly.



Collector: Attached to the largest of the semiconductor regions. Current flows through the collector to the emitter as controlled by the base.

Emitter: Attached to the second largest of the semiconductor regions. Current flows from the collector to the emitter when the base voltage allows.

Base: Attached to the middle semiconductor region. This region serves as a valve that controls how much current is allowed to flow through the collector-emitter circuit. When sufficient voltage is applied to the base, current is allowed to flow.

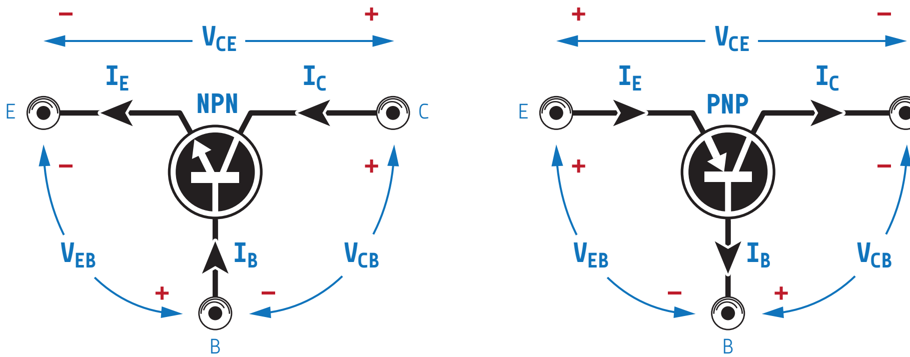
0-1.es/A7

A7

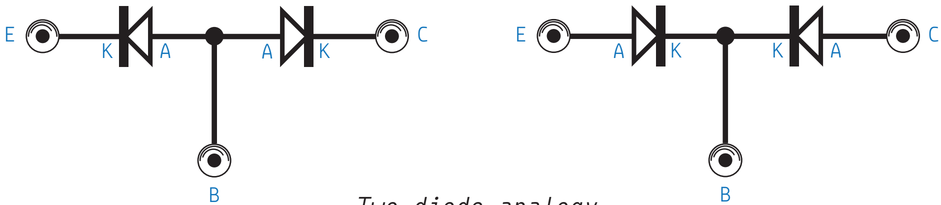
Transistors

Basic Concepts

Transistors are current-regulating devices that act as a current-controlled switches. The amount of current flowing through them varies proportionally with the amount of biasing voltage applied to their base terminal.



The schematic symbols for both transistors have their arrows pointing in the direction of the conventional current flow, between the base terminal and its emitter terminal. The direction of the arrow points from the positive p-type region to the negative n-type region for both transistor types, the same occurs with the standard diode symbol.

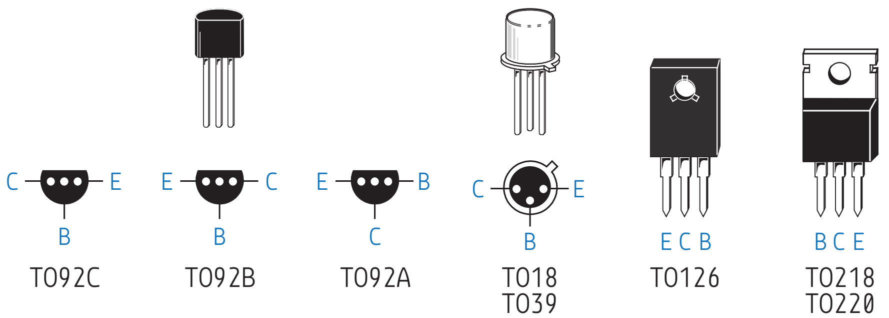


Two diode analogy

Transistors

Basic Concepts

Transistors come in a wide variety of physical packages. Package type is primarily dependent upon the required power dissipation of the transistor, with it physical size being proportional to its maximum power dissipation.



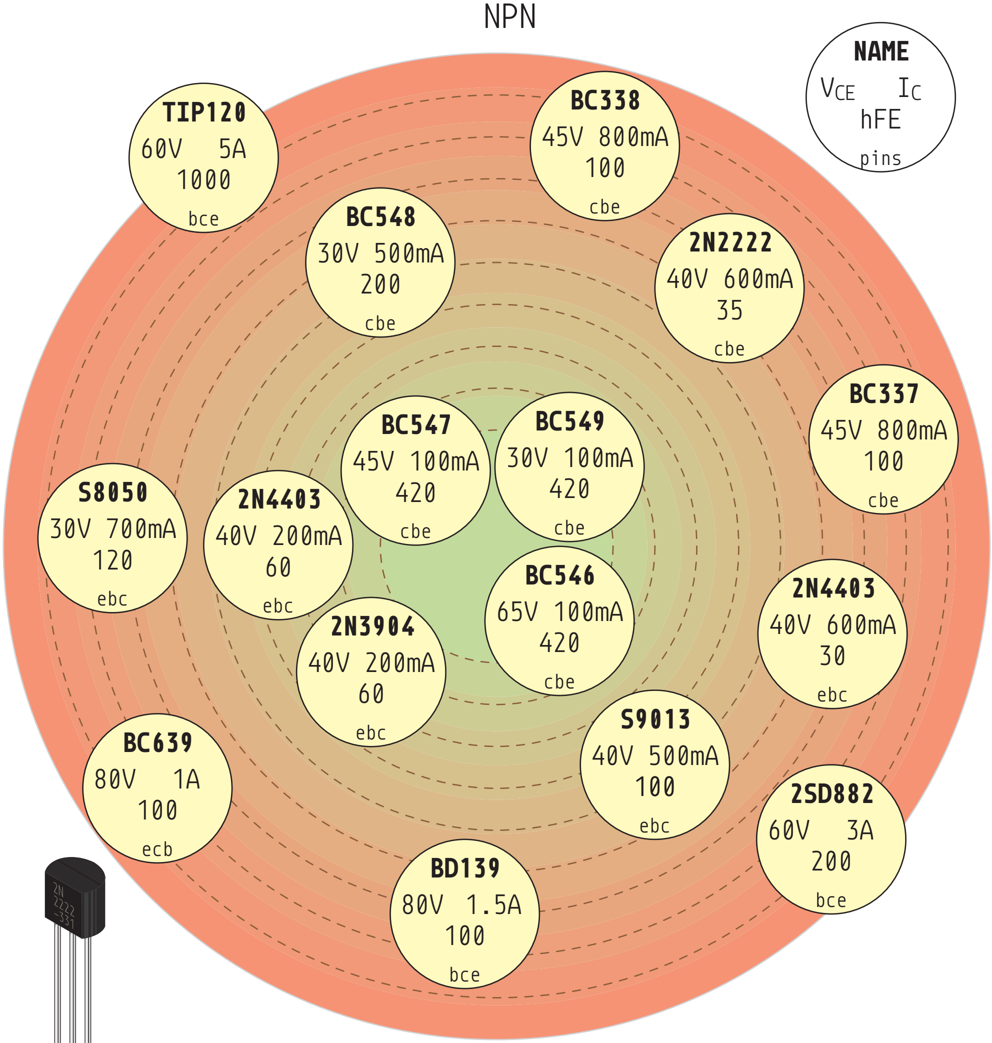
Note: It is very important to check the datasheet of each transistor since the pinouts are not standardized.

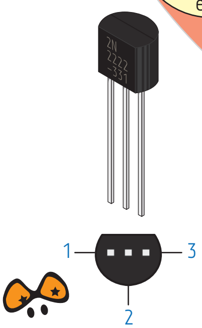
Symbol	Description
V_{CE}	**Collector-Emitter Voltage**
V_{EB}	**Emitter-Base Voltage**
V_{CB}	**Collector-Base Voltage**
I_E	**Emitter Current**
I_C	**Collector Current**
I_B	**Base Current**
hFE	**Current Gain**

Important transistor characteristics

Transistor Selector

NPN



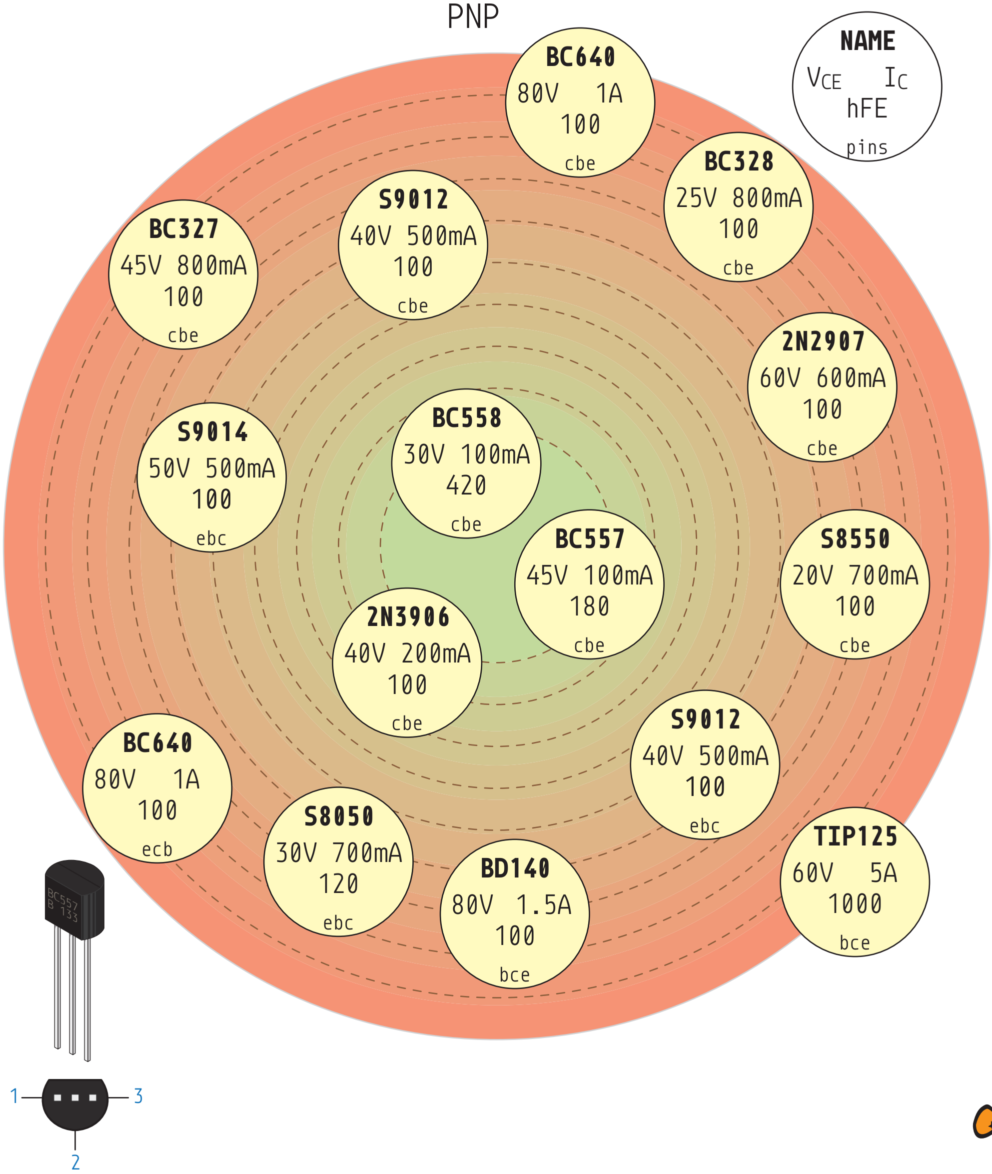


R7

0-1.es/R7

Transistor Selector

PNP

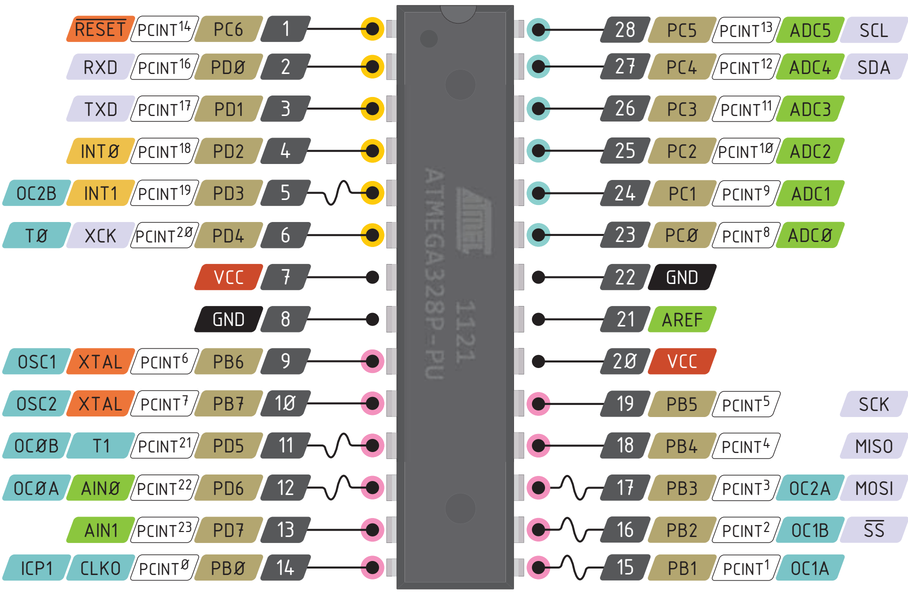


0-1.es/P1

P1

ATmega328P
Pinout

Absolute MAX per pin
40mA, 20mA recommended



Absolute MAX per pin 200mA for the entire package

The total current of each port power group should not exceed 100mA

- Power
- GND
- Physical PIN
- Port PIN
- Analog PIN
- Serial PIN
- PIN Function
- Interrupt PIN
- Control PIN

PWM Pin

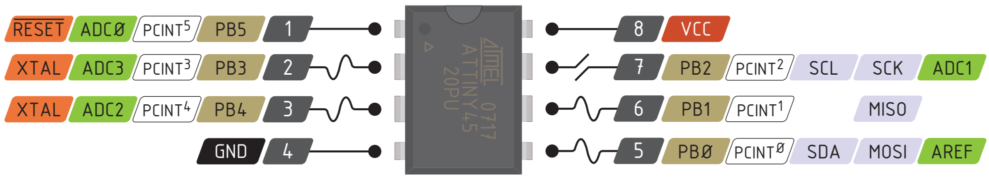
Port power group

P2

0-1.es/P2

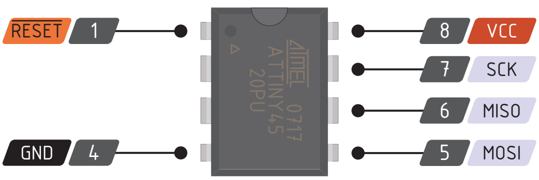
ATtiny85
Simplified Pinout

Absolute MAX per pin
10mA, 5mA recommended

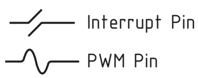


Absolute MAX per pin 60mA
for the entire package

ICSP Programming



- Power
- GND
- Physical PIN
- Port PIN
- Analog PIN
- Serial PIN
- PIN Function
- Interrupt PIN
- Control PIN

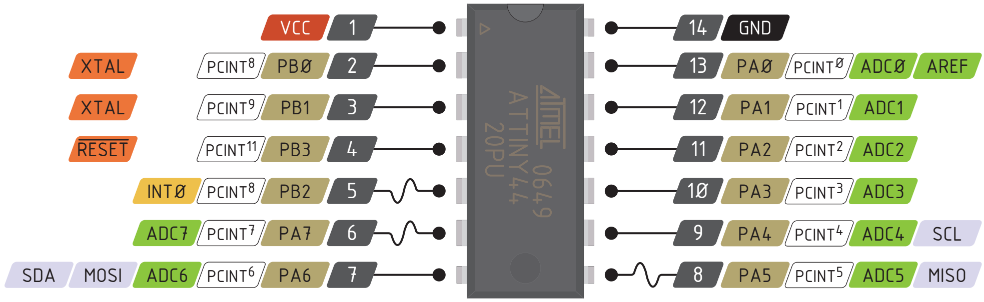


0-1.es/P3

P3

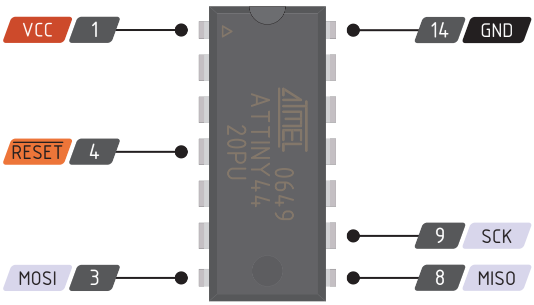
ATtiny84
Simplified Pinout

Absolute MAX per pin
10mA, 5mA recommended



Absolute MAX per pin 60mA
for the entire package

ICSP Programming



- Power
- GND
- Physical PIN
- Port PIN
- Analog PIN
- Serial PIN
- PIN Function
- Interrupt PIN
- Control PIN

PWM Pin

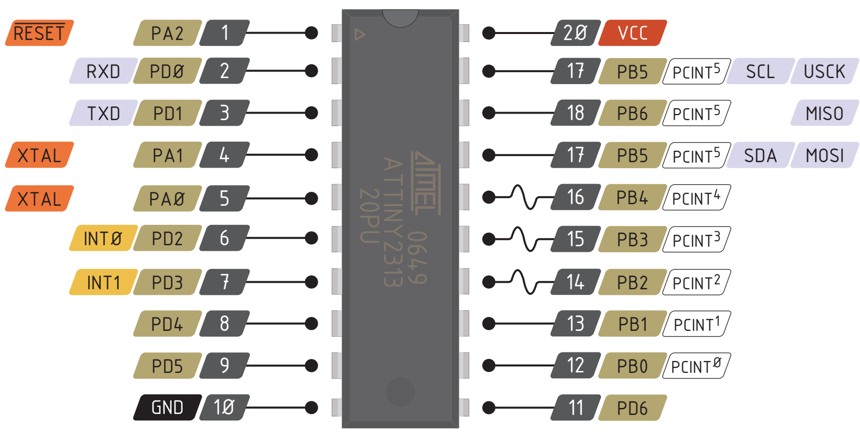
P4

0-1.es/P4

ATtiny2313

Simplified Pinout

Absolute MAX per pin
10mA, 5mA recommended



Absolute MAX per pin 60mA
for the entire package

- Power
- GND
- Physical PIN
- Port PIN
- Analog PIN
- Serial PIN
- PIN Function
- Interrupt PIN
- Control PIN

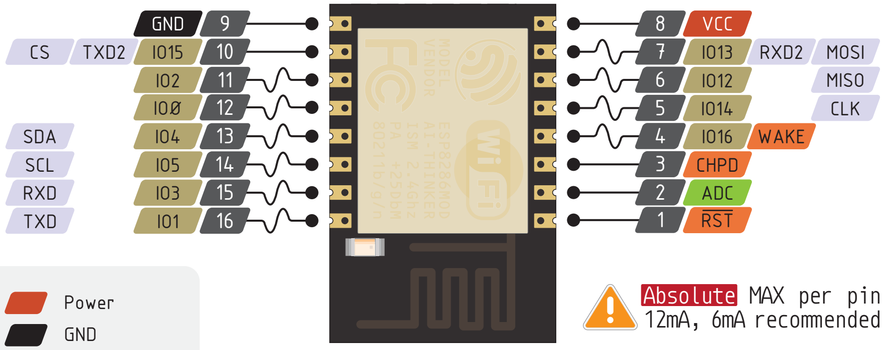
PWM Pin

0-1.es/P5

P5

ESP8266
Simplified Pinout

ESP-12S



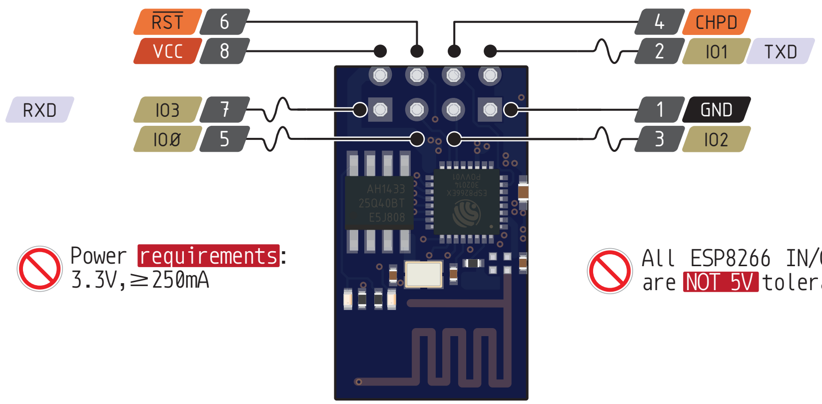
Absolute MAX per pin
12mA, 6mA recommended

- Power
- GND
- Physical PIN
- Port PIN
- Analog PIN
- Serial PIN
- Control PIN

IO15	IO0	IO2	Boot Mode
0V	**0V**	**3.3V**	UART Bootloader
0V	**3.3V**	**3.3V**	Boot Sketch (SPI Flash)

PWM Pin

ESP-01



Power requirements:
3.3V,≥250mA

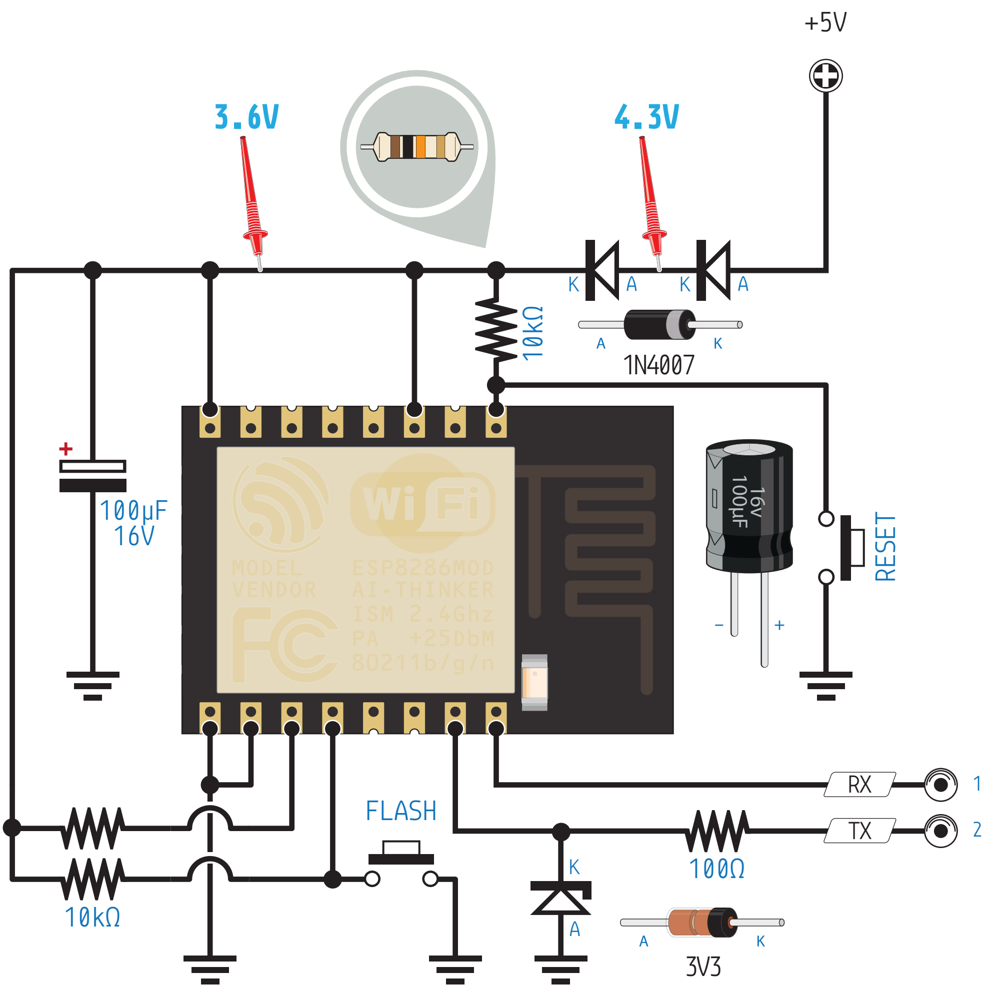
All ESP8266 IN/OUTs
are NOT 5V tolerant!

P5

0-1.es/P5

ESP8266

ESP-12S Minimal Setup



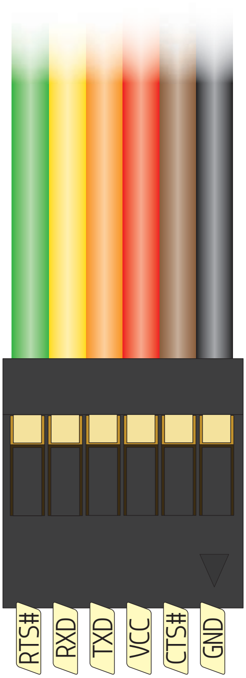
Don't forget to connect all
the ground wires together!

0-1.es/P6

P6

FTDI

Pinout



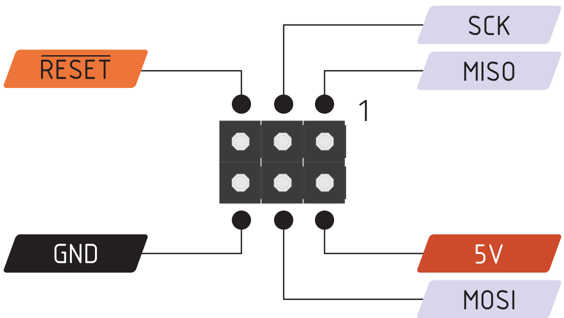
Check the I/O pin voltage before programming the microcontroller!

The FTDI cable is a USB to Serial (TTL level) converter which allows for a simple way to connect TTL interface devices to USB. Normally the I/O pins of FTDI cable are configured to operate at 5V. The FTDI cable uses the RTS signal for hardware reset when programming a microcontroller board.

P7

0-1.es/P7

ICSP
Pinout



The ICSP header allows the microcontroller to receive the firmware or the bootloader. **ICSP** stands for In Circuit Serial Programming, it is a standard way to program AVR chips. ISCP uses six pins to program the microcontroller:

MISO: (Master In Slave Out): the slave line for sending data to the master.

MOSI: (Master Out Slave In): the master line for sending data to the peripherals.

SCK: (Serial Clock): the clock pulses that synchronize data transmission generated by the master.

RESET: connected to the reset signal of the microcontroller.

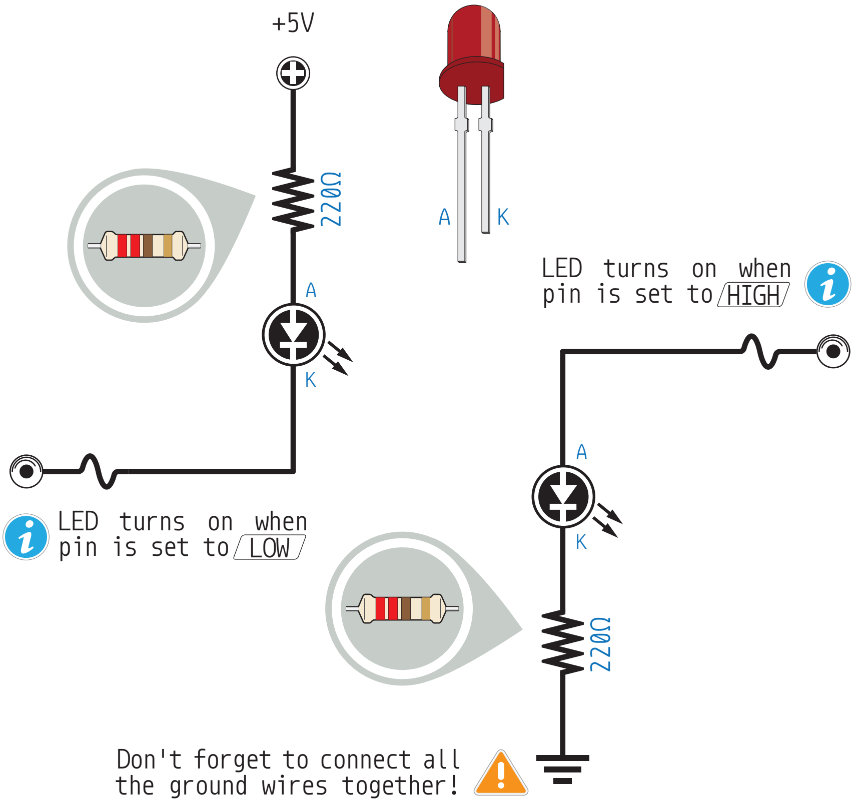
0-1.es/1

1

LED

Basic Connections

Reversing the polarity will not damage the LED



LED turns on when pin is set to HIGH

LED turns on when pin is set to LOW

Don't forget to connect all the ground wires together!

LEDs (ligth-emitting diodes) are components that are polarized and only allow current to flow in one direction. LEDs normally have two terminals: the anode (A) or positive side (the longer lead), and the cathode (K) or negative side (the shorter lead closest to the flat edge of the LED).

1

0-1.es/1

LED
Test Code

```
int LEDPin = 13;                      // Assign variable LEDPin as pin 13

void setup() {
     pinMode(LEDPin,OUTPUT);          // Initialize the pin as an OUTPUT
}

void loop() {
     digitalWrite(LEDPin,HIGH);       // Turn the LED ON
     delay(1000);                     // Wait for 1 second
     digitalWrite(LEDPin,LOW);        // Turn the LED OFF
     delay(1000);                     // Wait for 1 second
}
```

Typical LED Current Limiting Resistor Values

Red	220Ω
Green	180Ω
Blue	100Ω
Orange	200Ω
White	100Ω

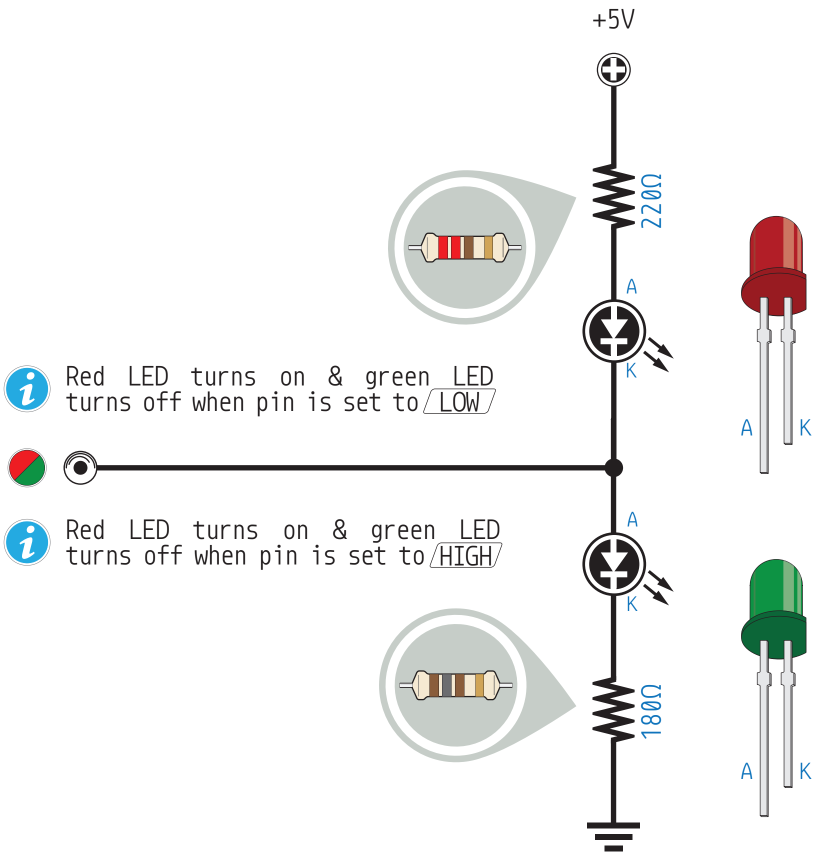
Limiting the current that flows through an LED is very important! For this purpose, a current limiting resistor is used in series with the LED. If you connect the LED directly (without a resistor in series) the microcontroller or the LED may suffer damage!

0-1.es/2

2

Alternating LEDs

Basic Connections

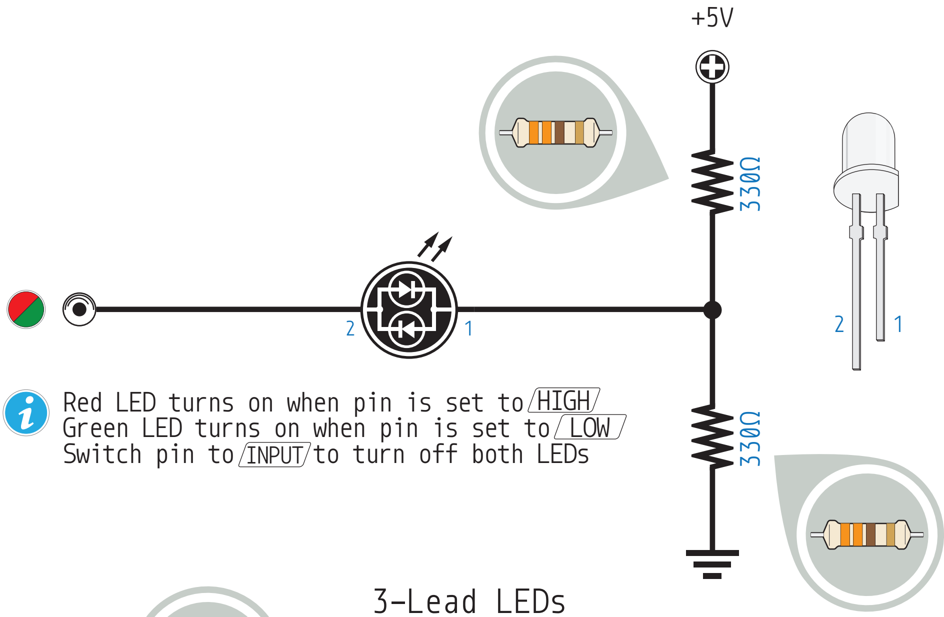


3

0-1.es/3

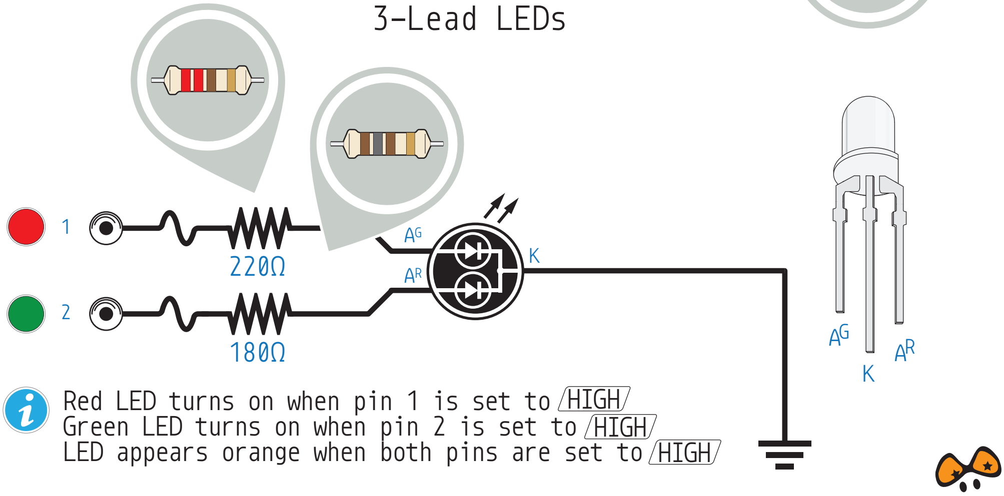
Bi-Color LED

2-Lead LEDs



Red LED turns on when pin is set to HIGH
Green LED turns on when pin is set to LOW
Switch pin to INPUT to turn off both LEDs

3-Lead LEDs

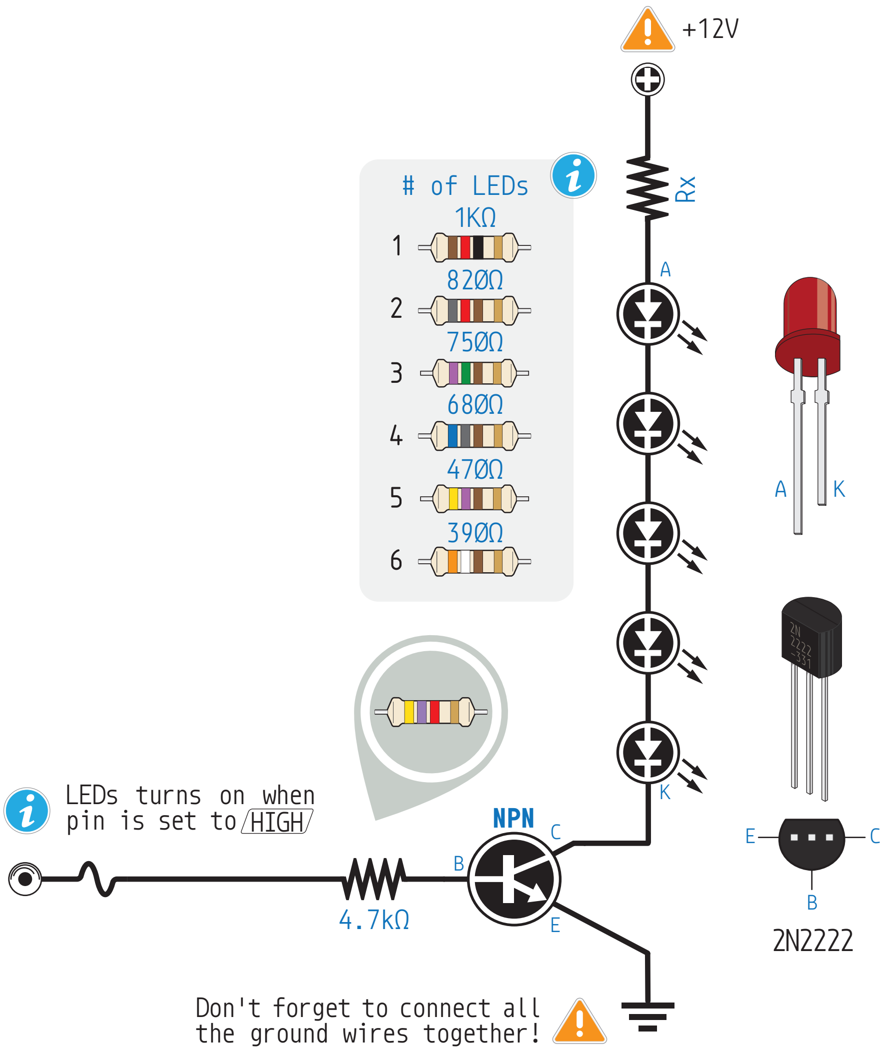


Red LED turns on when pin 1 is set to HIGH
Green LED turns on when pin 2 is set to HIGH
LED appears orange when both pins are set to HIGH

0-1.es/4

LED Cluster

Basic Connections



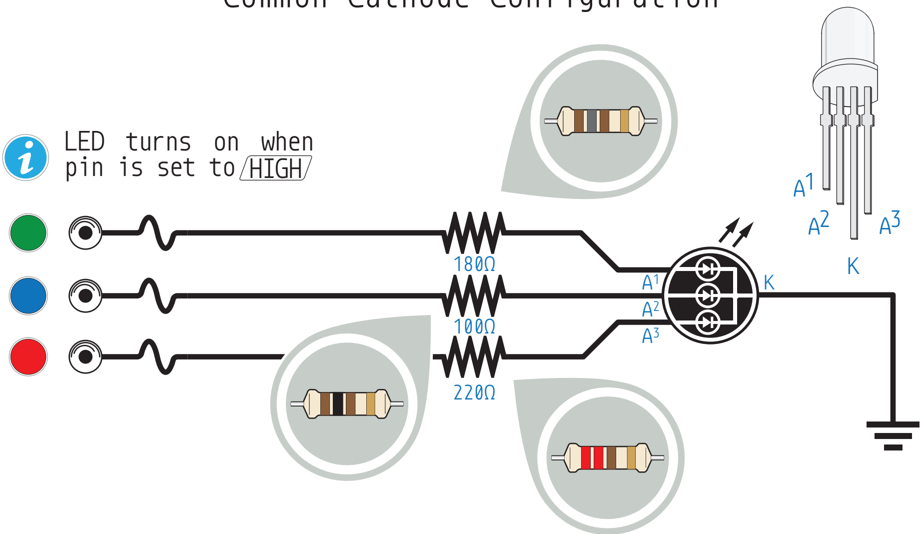
5

0-1.es/5

RGB LED

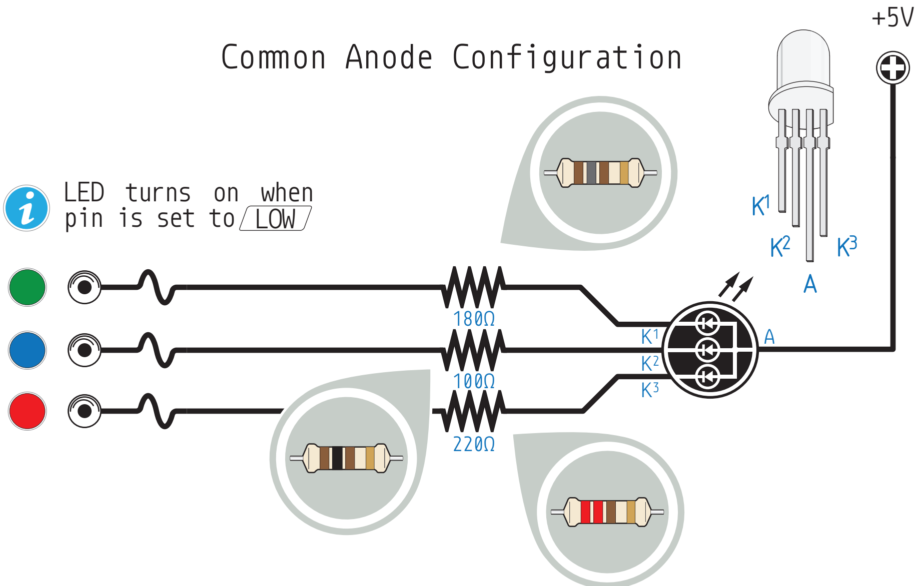
Common Cathode Configuration

LED turns on when pin is set to HIGH



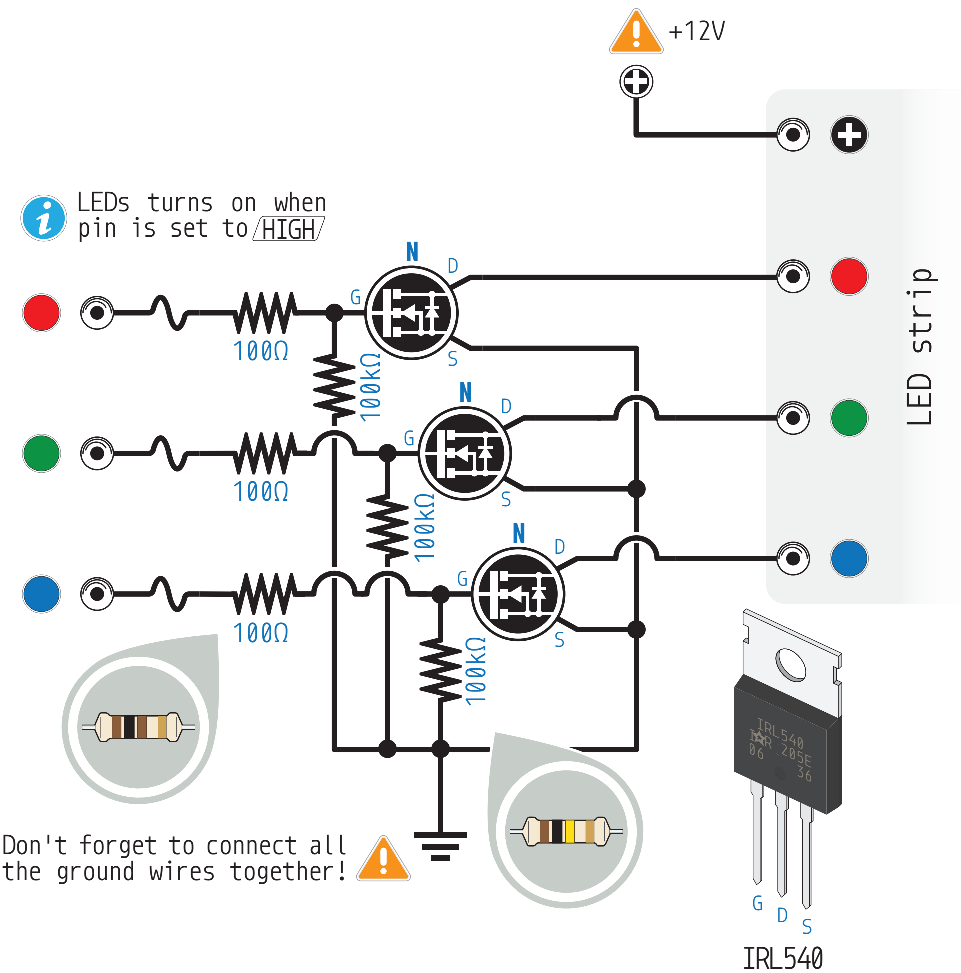
Common Anode Configuration

LED turns on when pin is set to LOW



LED Strip

Basic Connections



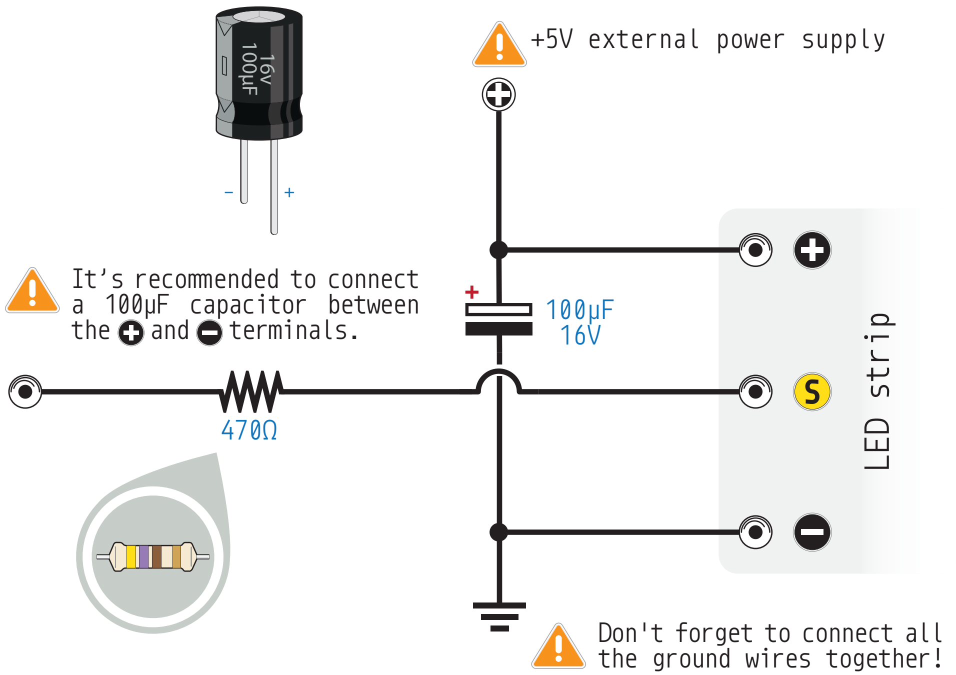
A 1 meter long LED strip can draw nearly 1A when all LEDs are on full brightness. The I/O pins of most microcontroller boards can only supply up to 40mA each, so you will have to help it out with a driver circuit to boost the power. This circuit uses 3 PWM signals from the board and uses them to drive 3 MOSFETs.

7

0-1.es/7

Digitally-Addressable LEDs

Basic Connections



When connecting digitally-addressable LEDs to any LIVE power source or microcontroller, ALWAYS CONNECT GROUND (⊖) BEFORE ANYTHING ELSE. Conversely, disconnect ground last when detaching the LEDs.

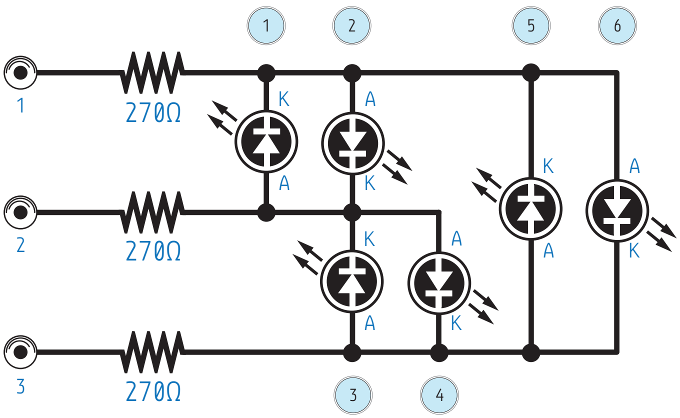
This schematic is valid only for RGB color pixels and strips based on the WS2812, WS2811 and SK6812 LED drivers, which use a single-wire control protocol. Do not power the strip directly from the 5V pin of the microcontroller board! Each individual LED draws up to 60mA when set to white at maximum brightness.

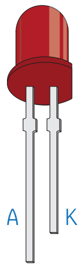
0-1.es/8

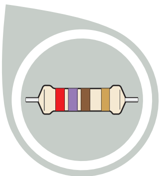
8

Charlieplexing

Basic Connections







1	2	3	LED
LOW	HIGH	INPUT	1
HIGH	LOW	INPUT	2
INPUT	LOW	HIGH	3
INPUT	HIGH	LOW	4
LOW	INPUT	HIGH	5
HIGH	INPUT	LOW	6

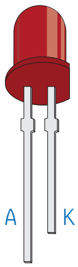
Charlieplexing is a technique for driving a multiplexed display in which relatively few I/O pins on a microcontroller are used to drive an array of LEDs. Not only does it take advantage of the two states that we normally change, HIGH and LOW, but it also uses a third state by changing between OUTPUT and INPUT modes.

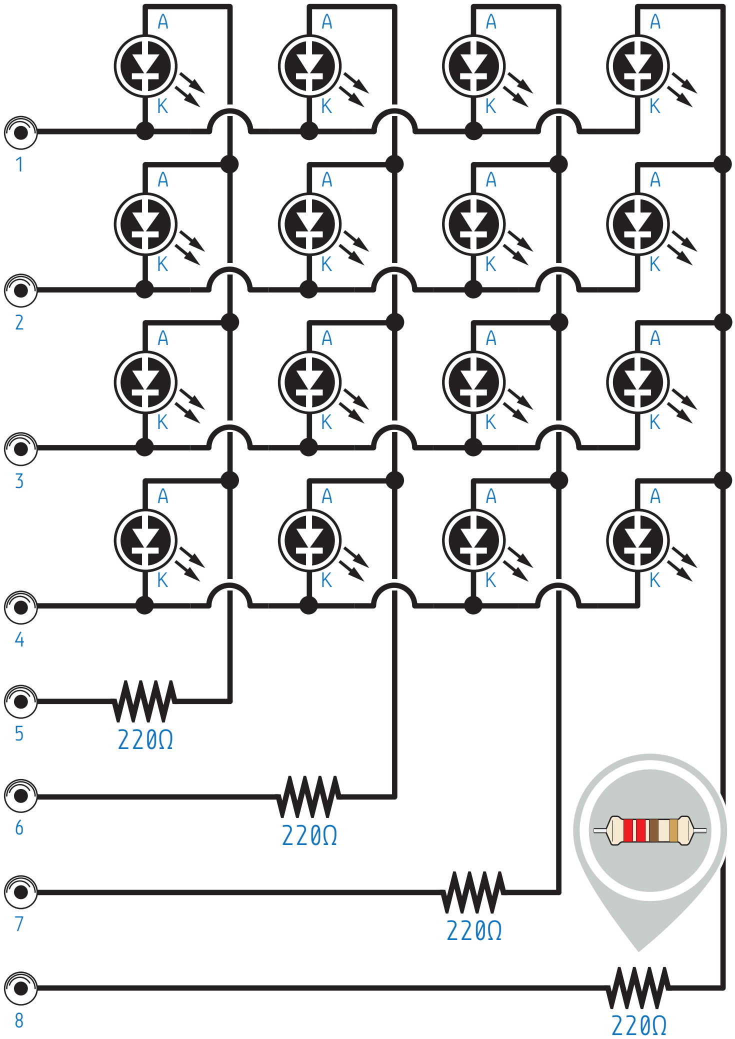
9

0-1.es/9

LED Matrix

Basic Connections



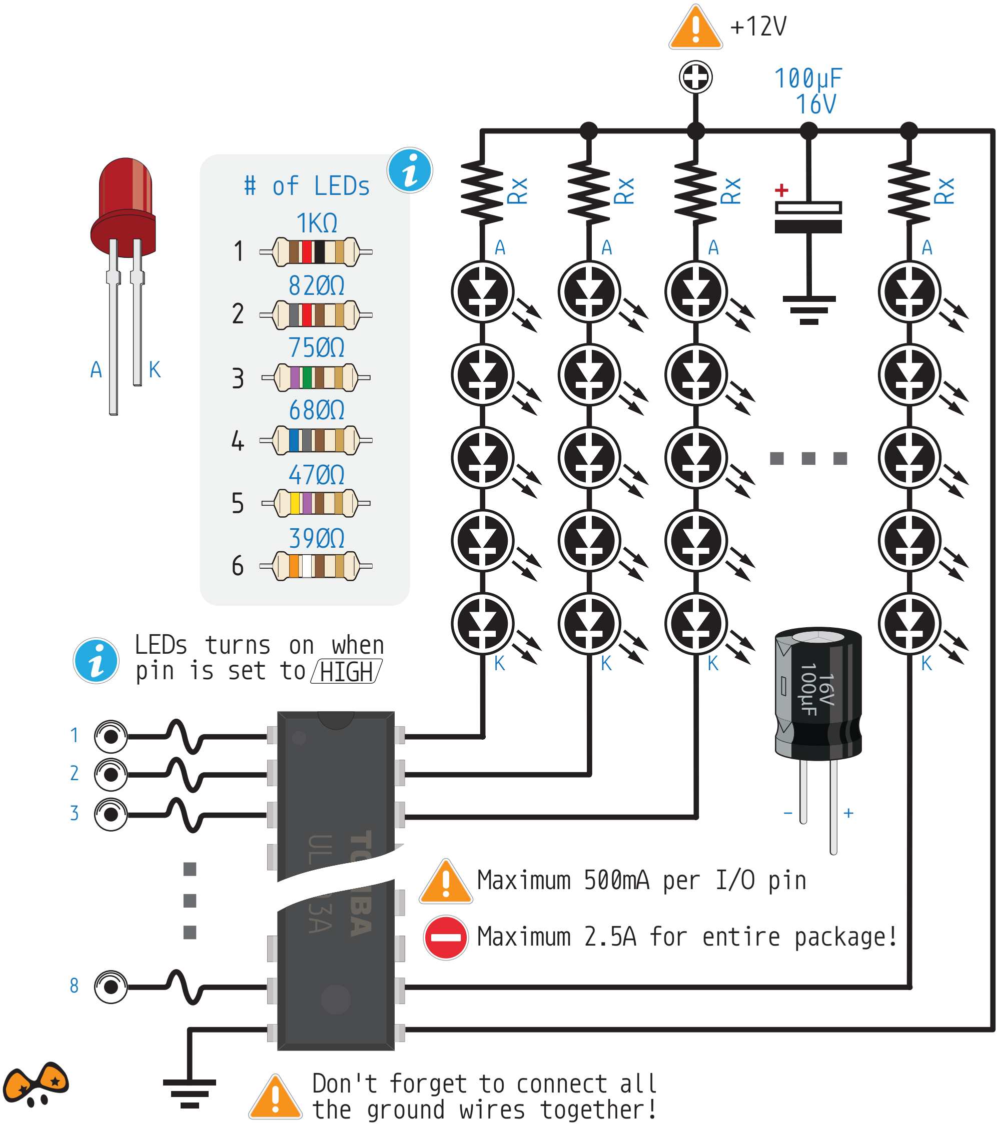


0-1.es/10

10

Multiple LED Clusters

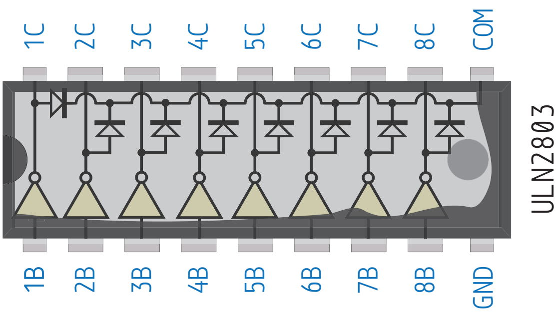
Using the ULN2803 Darlington Transistor Array



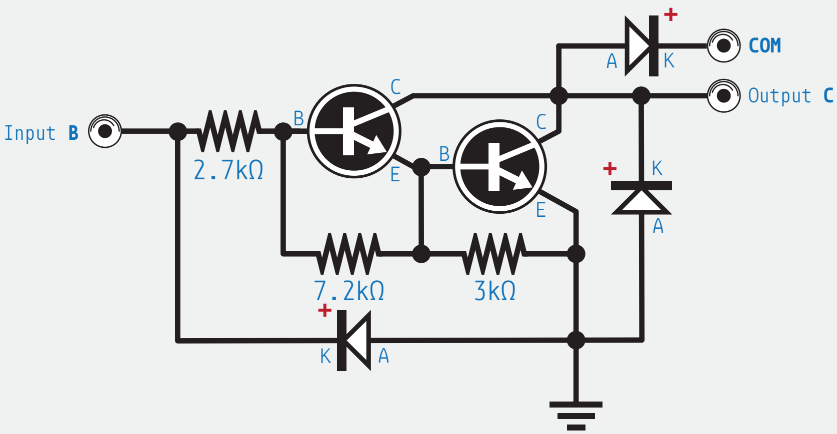
10

0-1.es/10

ULN2803
Pinout



Port Schematic



The ULN2803 is an octal Darlington transistor array that delivers up to 500mA of current for each pin and operates at up to 50V. You can drive motors, DC light bulbs, relays, solenoids, etc. The Darlington output pins can even be connected in parallel for higher current applications.

0-1.es/11

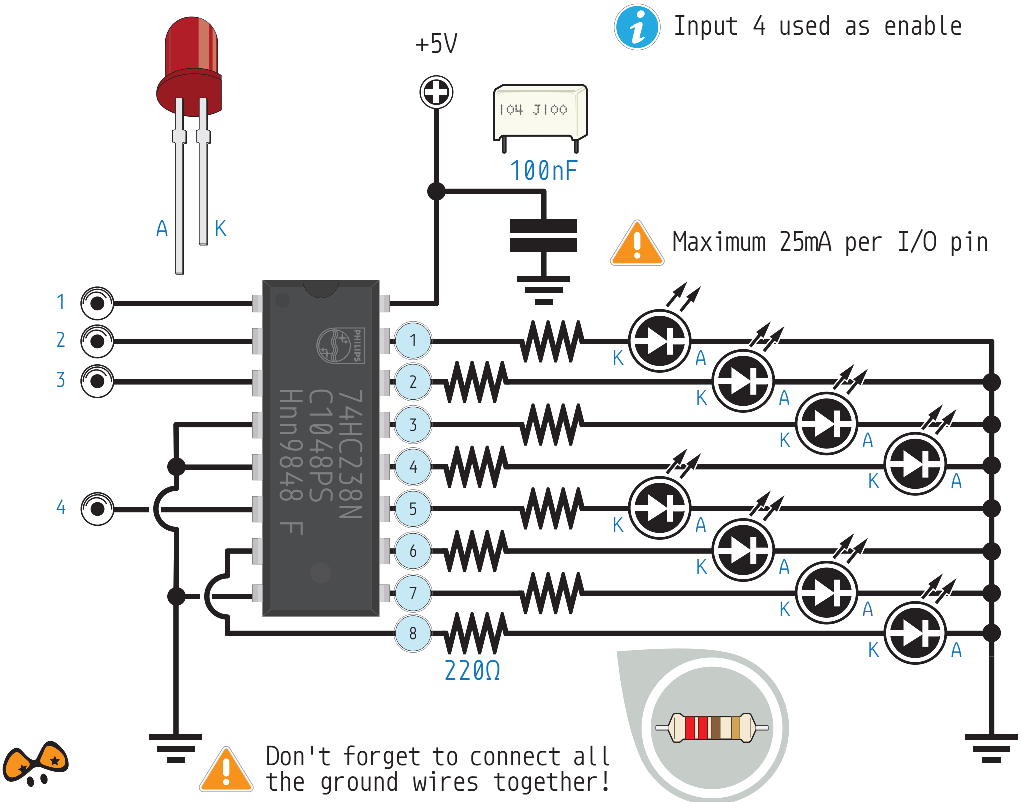
11

Decoder/Demultiplexer

Using the 74HC238 Decoder

1	2	3	LED
LOW	LOW	LOW	1
HIGH	LOW	LOW	2
LOW	HIGH	LOW	3
HIGH	HIGH	LOW	4
LOW	LOW	HIGH	5
HIGH	LOW	HIGH	6
LOW	HIGH	HIGH	7
HIGH	HIGH	HIGH	8

Input 4 used as enable



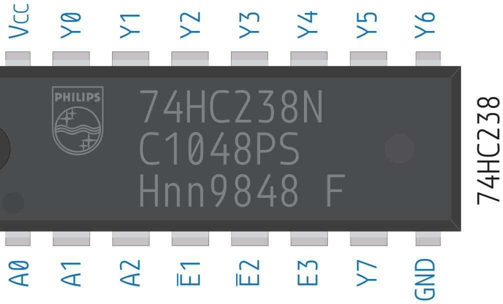
Maximum 25mA per I/O pin

Don't forget to connect all the ground wires together!

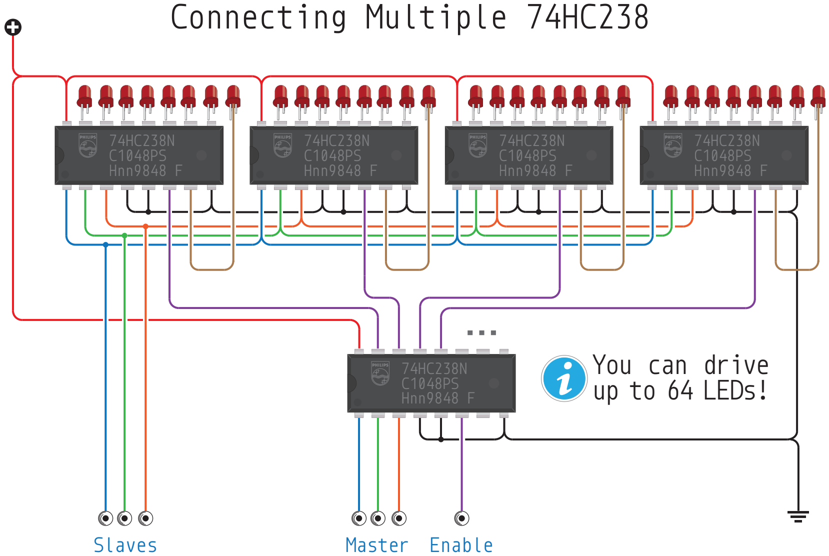
11

0-1.es/11

74HC238
Pinout



Connecting Multiple 74HC238



The 74HC238 is a high speed CMOS 3-to-8 line decoder. It has three binary select inputs (A0, A1, A2) which determine which one of the eight outputs (Y0-Y7) will go high. This chip has three enable inputs (E1, E2, E3). If you leave E3 low, no outputs can be set to high.

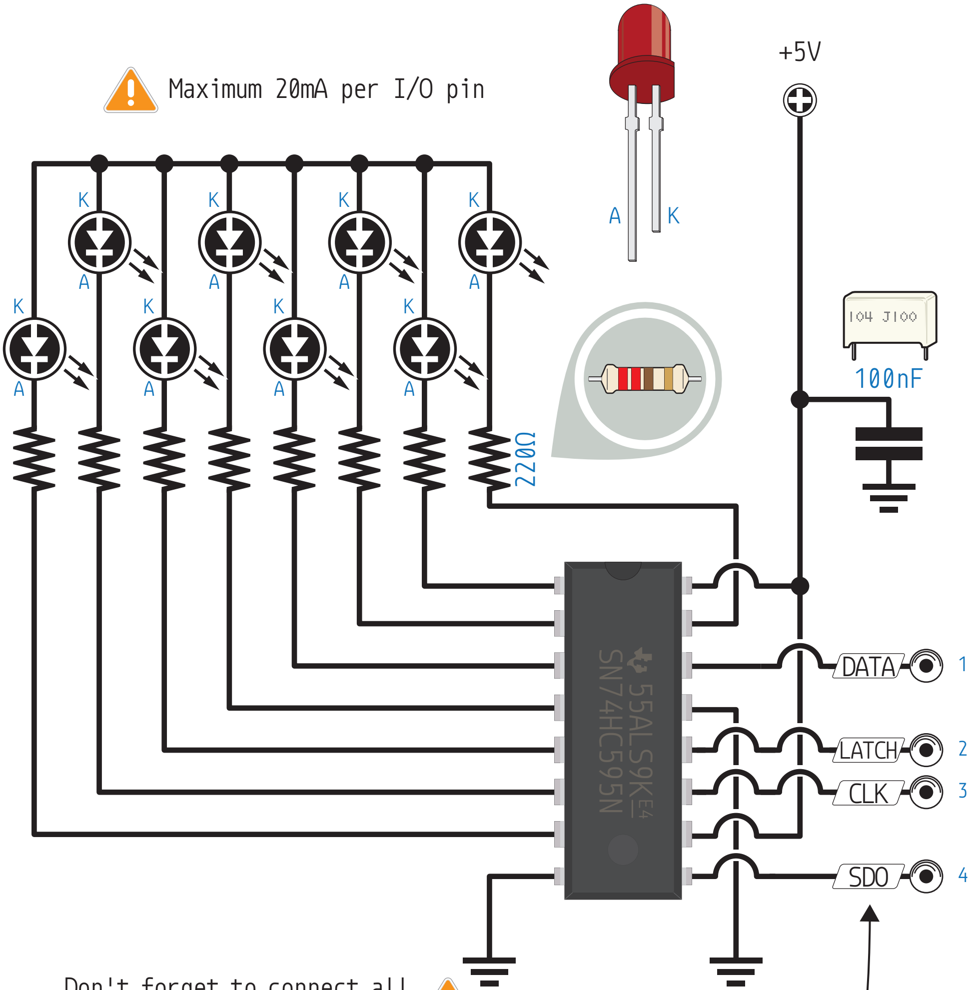
0-1.es/12

12

Shift Register

Using the 74HC595 Shift Register

Maximum 20mA per I/O pin



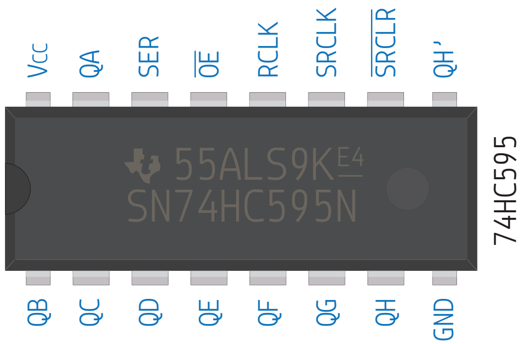
Don't forget to connect all the ground wires together!

SDO outputs the over-flown bit to be shifted

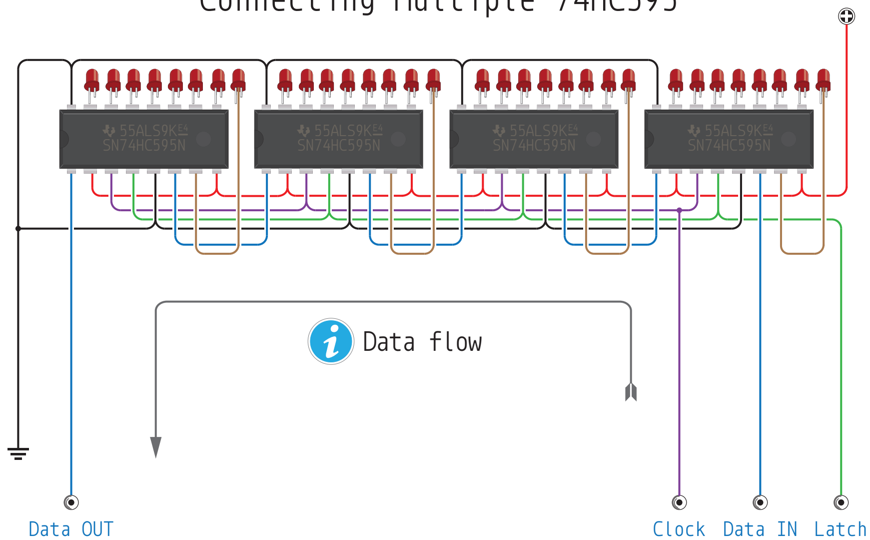
12

0-1.es/12

74HC595
Pinout



Connecting Multiple 74HC595



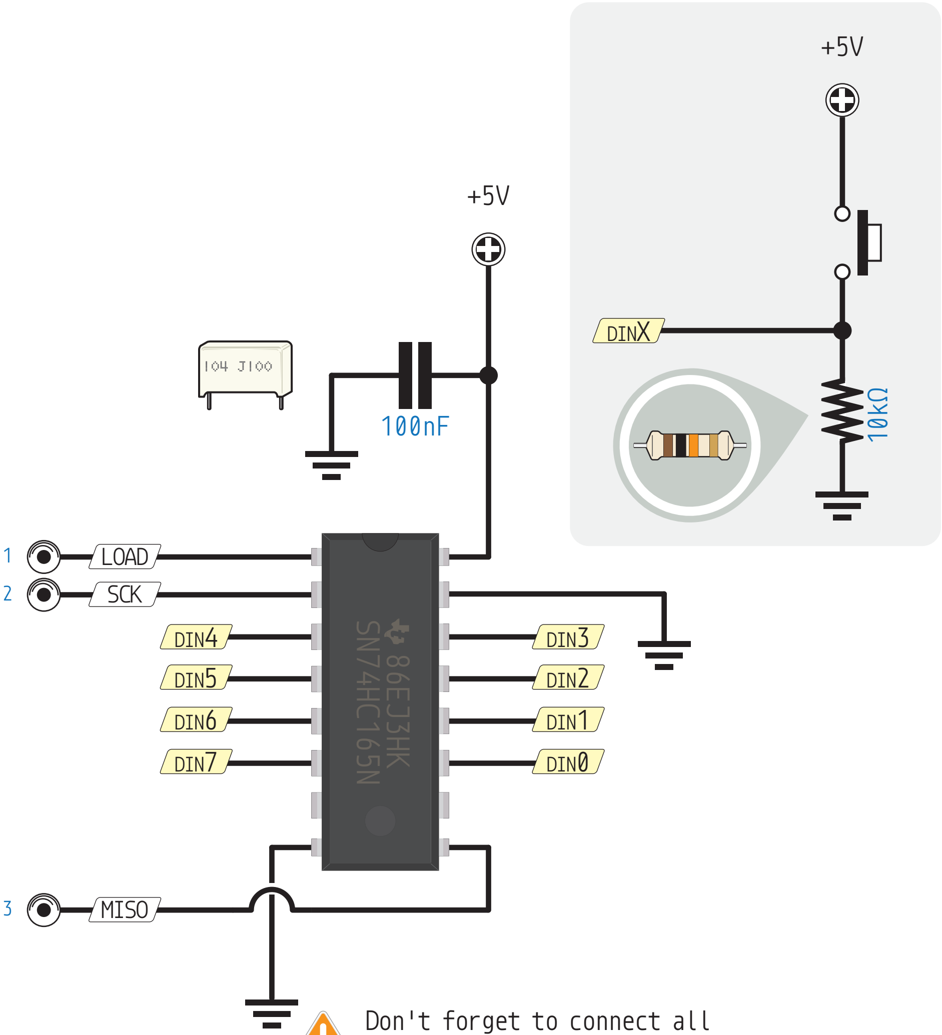
The 74HC595 is an 8-bit shift register. It takes 8 bits from the serial input and outputs them to 8 pins. You can daisy chain them together so it's really easy to control a big number of LEDs or power transistors from only 3 digital microcontroller pins.

0-1.es/13

13

Input Shift Register Via SPI

Using the 74HC165 Shift Register

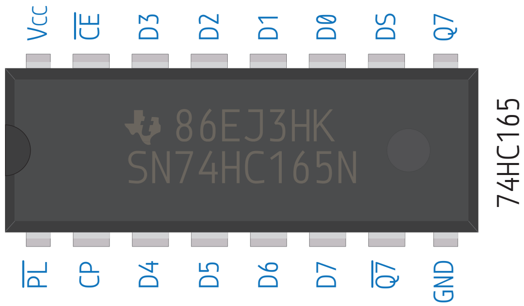


Don't forget to connect all the ground wires together!

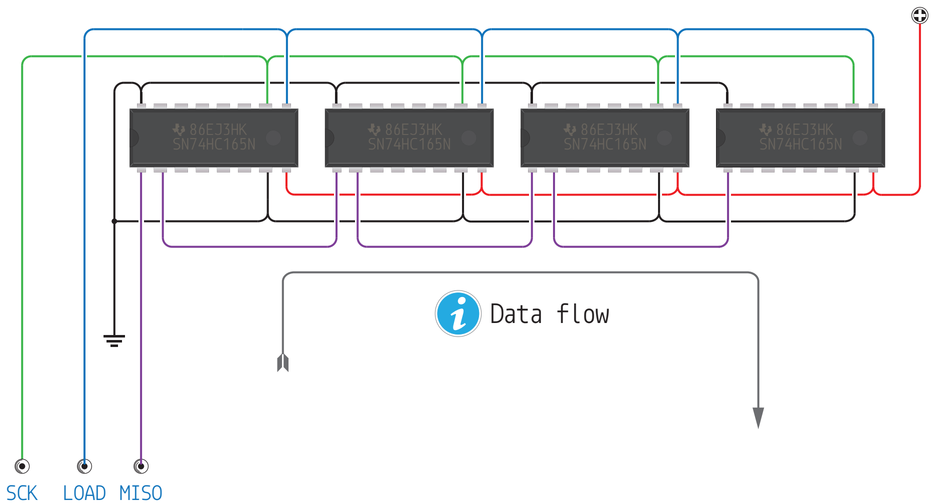
13

0-1.es/13

74HC165
Pinout



Connecting Multiple 74HC165



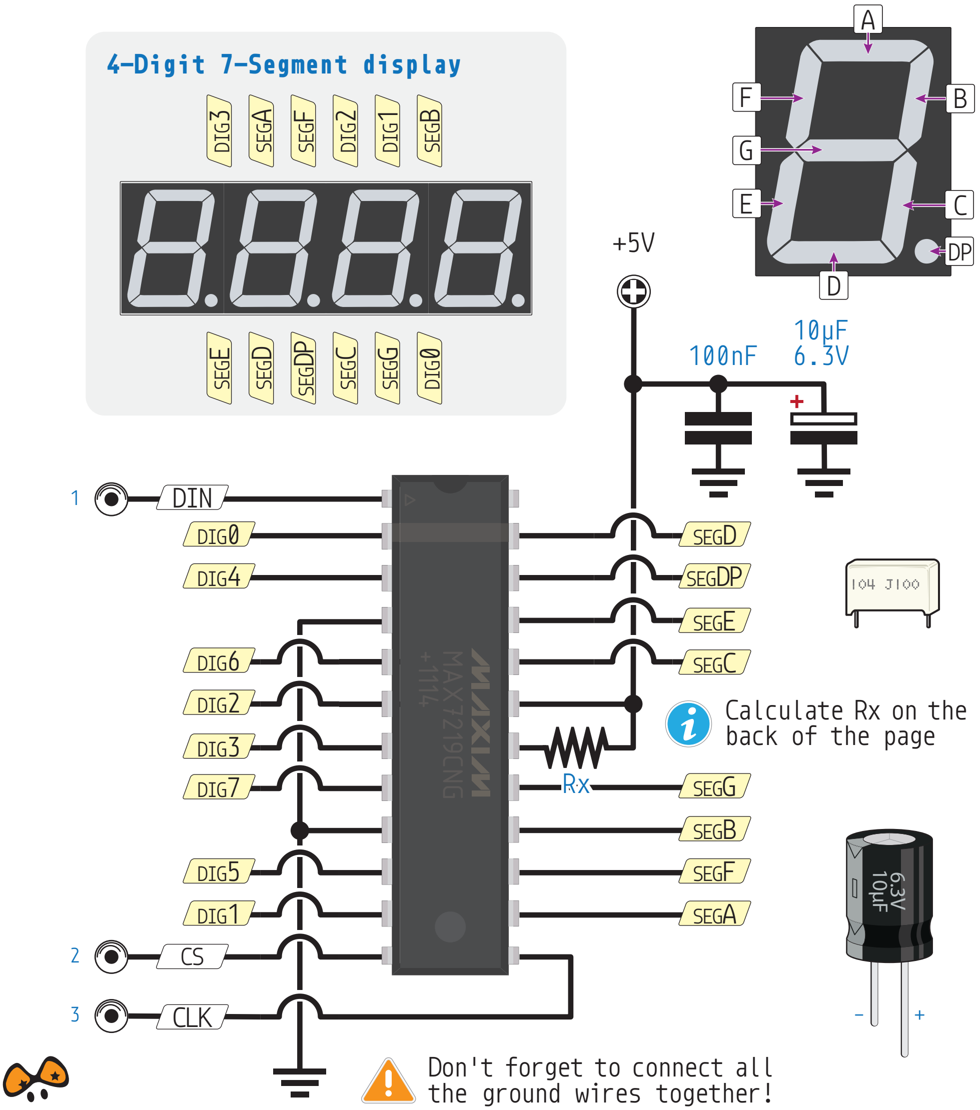
The 74HC165 is an 8-bit parallel-load or serial-in shift registers with complementary serial outputs available from the last stage. You can daisy chain them together so it's really easy to control a big number of LEDs or power transistors from only 3 digital microcontroller pins.

0-1.es/14

14

MAX7219 7-Seg. Display Driver

Connecting a 4-Digit 7-Segment Display



Calculate Rx on the back of the page

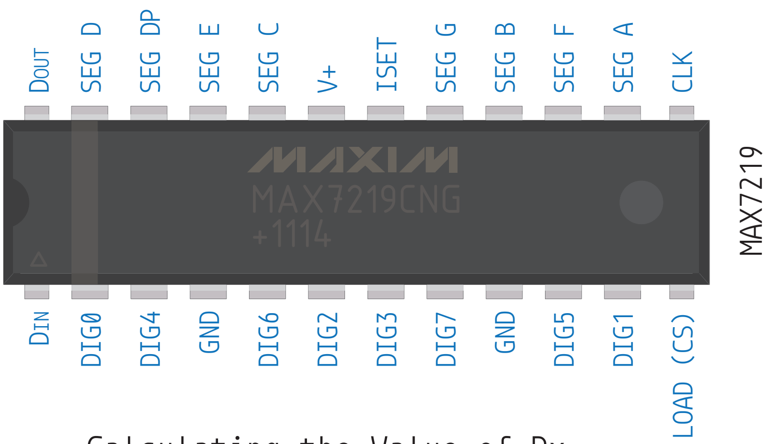
Don't forget to connect all the ground wires together!

14

0-1.es/14

MAX7219

Pinout



Calculating the Value of Rx

The MAX7219 is a constant-current LED driver. Resistor Rx is used to set the current for the LEDs. You will need to know the voltage and forward current for your LED display or matrix and match the value on the table below. E.g., if you have a 2V, 20mA LED, your resistor value must be 28kΩ.

I_{SEG} (mA)	V_{LED} (V)				
	1.5	**2.0**	**2.5**	**3.0**	**3.5**
40	12.2	11.8	11.0	10.6	9.69
30	17.8	17.1	15.8	15.0	14.0
20	29.8	28.0	25.9	24.5	22.6
10	66.7	63.7	59.3	55.4	51.2

Values in kΩ

The MAX7219 is a powerful serial input/output common-cathode display driver that interfaces microcontrollers with 7-segment numeric LED displays of up to 8 digits. It has a built-in BCD decoder and brightness control. You could also use it to drive individual LEDs, Bar-graphs LEDs, or 8×8 LED matrix displays.

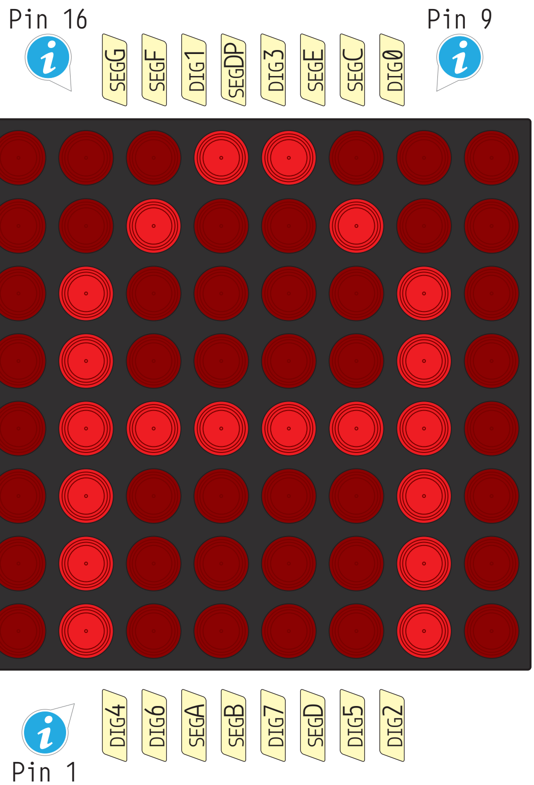
0-1.es/15

15

LEDM88G 8x8 LED Matrix

Using the MAX7219 LED Display Driver

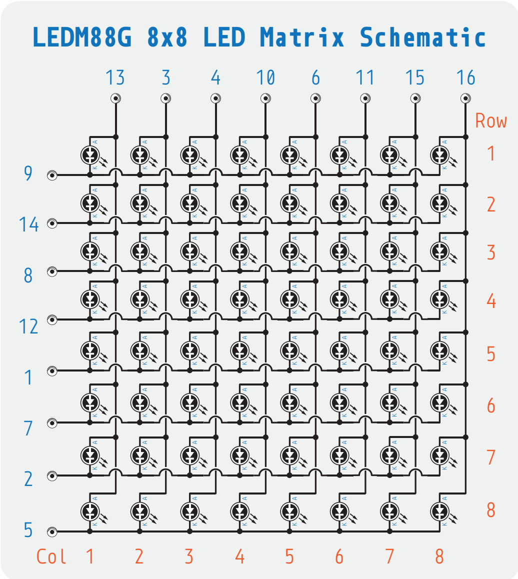
Use a common-cathode LED matrix

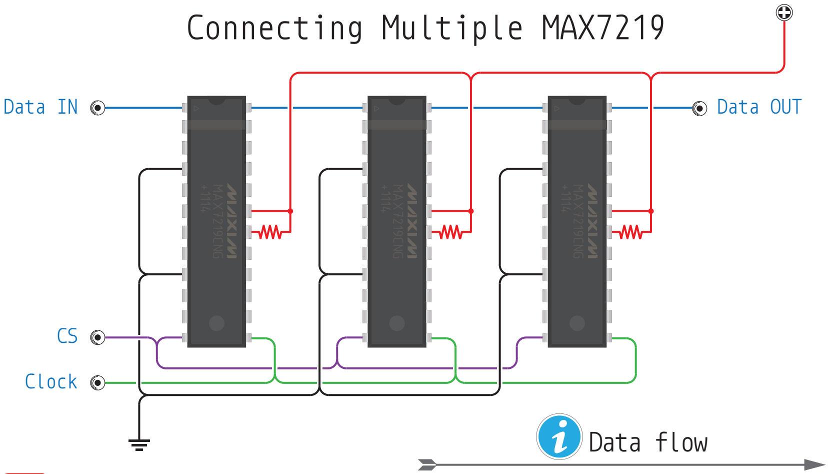


Pin 1 is the first pin starting from the left if you orient the device so that the part number is facing towards you

15

0-1.es/15





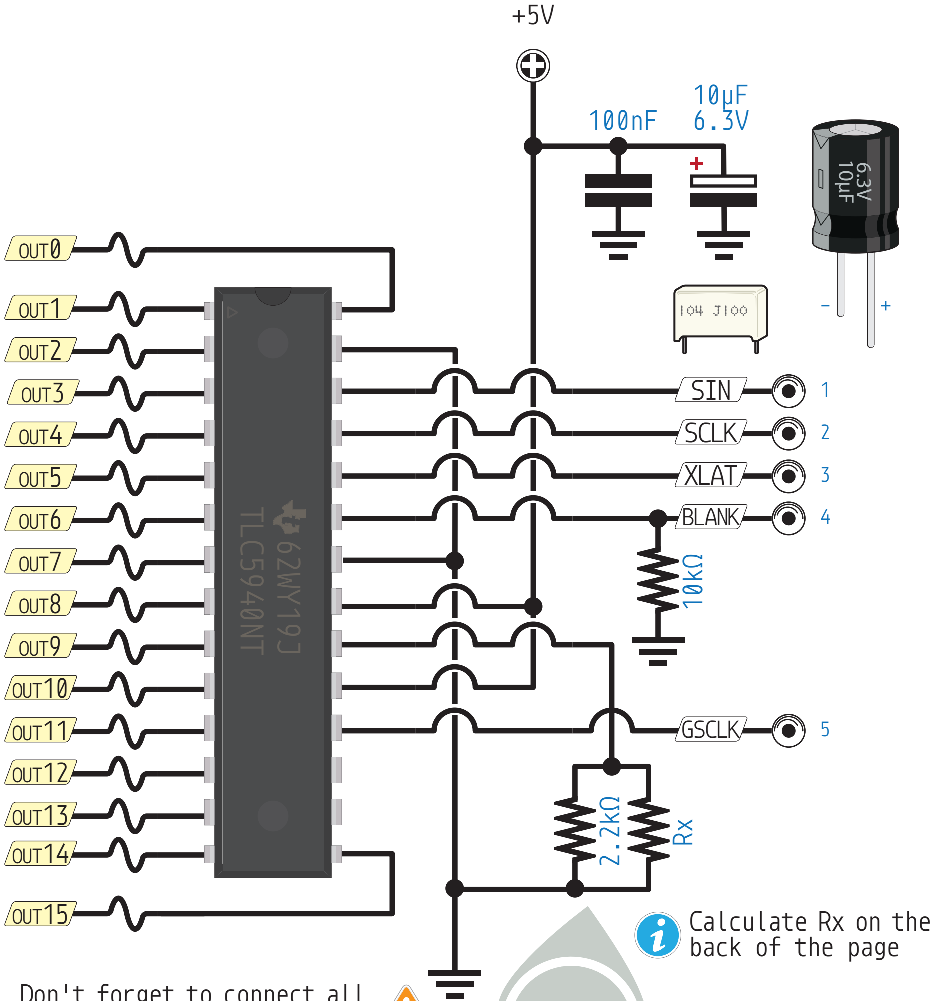
Using one MAX7219 you can drive up to 64 LEDs using only 4 wires to interface with a microcontroller. This powerful LED driver is designed to be daisy-chained so you can connect multiple 64-pixel displays together (like those scrolling signs you see in shop windows).

0-1.es/16

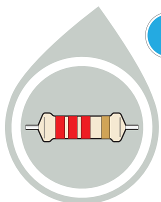
16

TLC5940 LED Driver

Basic Connections



Calculate Rx on the back of the page



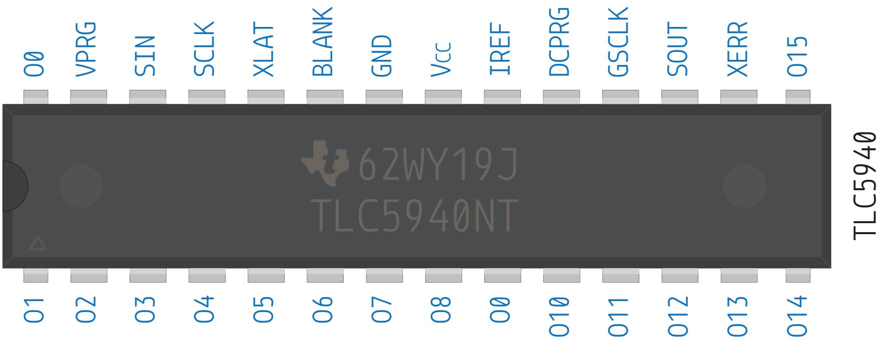
Don't forget to connect all the ground wires together!

16

0-1.es/16

TLC5940

Pinout



Calculating the value of Rx

The TLC5940 is a constant-current LED driver. The value of Rx has to be calculated according to the output current that is best suited for your application. If you want to connect components that draw 18mA of current use Ohm's law to calculate the resistor value as shown below.

$$Rx = V / I$$

$$Rx = 39.06V / 0.018A$$

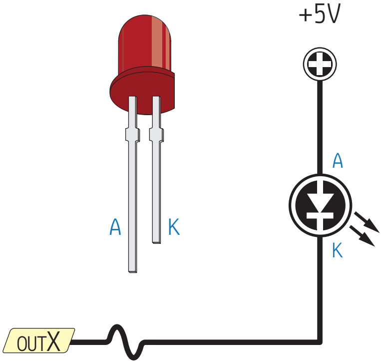
$$Rx = 2.170 \approx \mathbf{2.2k\Omega}$$

The number 39.06 comes from the on-chip 1.24V voltage reference multiplied by a gain of 31.5, therefore 1.24 × 31.5 = 39.06V

The TLC5940 is a 16-channel, constant-current sink LED driver. Each channel has an individually adjustable 4096-step grayscale PWM brightness control, 6 bit current limit control (0-63), and a daisy chainable serial interface. Use this schematic to increase the number of PWM pins available to your microcontroller.

TLC5940 LED Driver

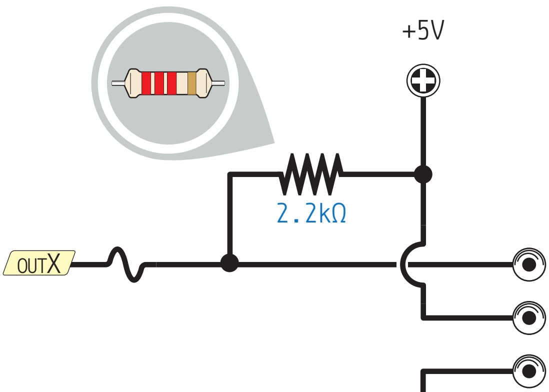
Connecting LEDs

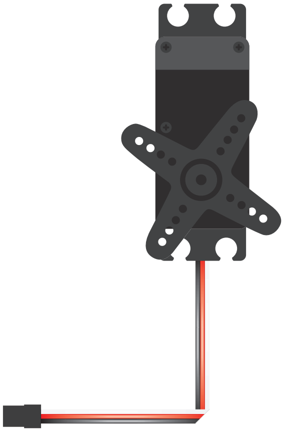


You can connect outputs in parallel to sink different current levels

Paralleleds outputs	LED current range (mA)	Number of LEDs per chip
1	**0-80**	16
2	**0-160**	8
3	**0-240**	5
6	**0-480**	2
8	**0-640**	2
16	**0-1280**	1

Connecting Servos





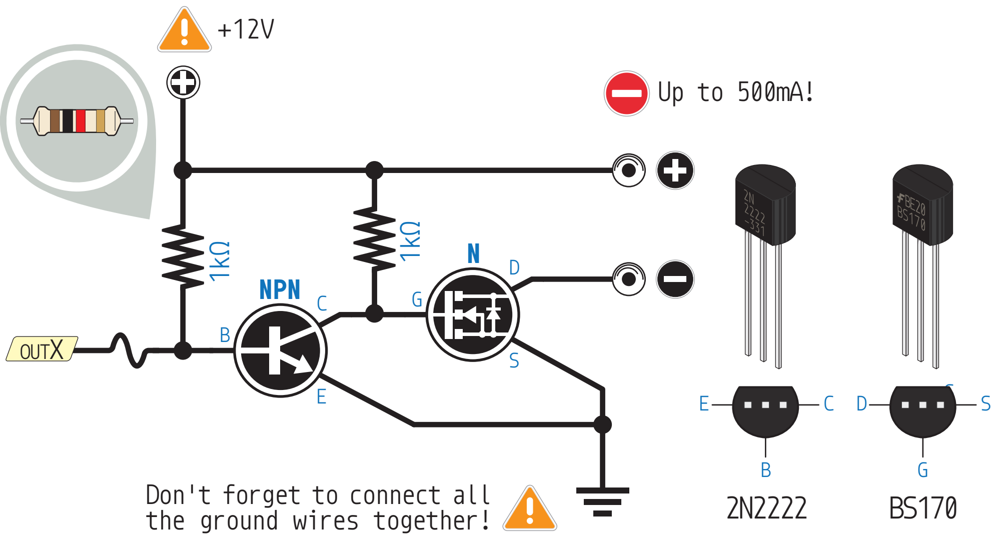
Don't forget to connect all the ground wires together!

16

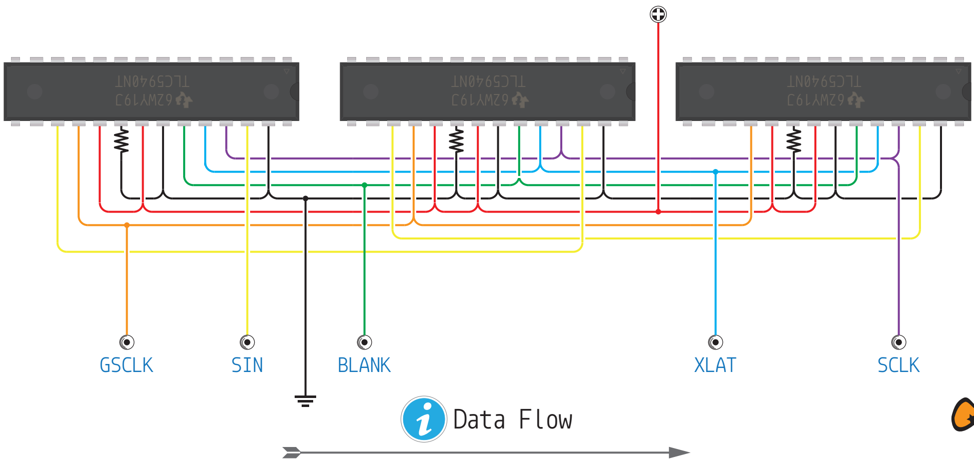
0-1.es/16

TLC5940 LED Driver

Connecting High-Power LEDs



Connecting Multiple TLC5940

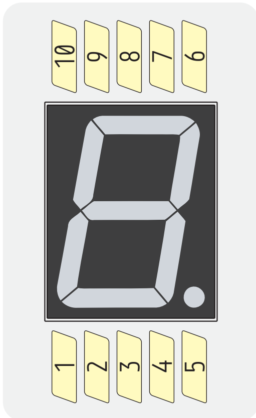


0-1.es/17

17

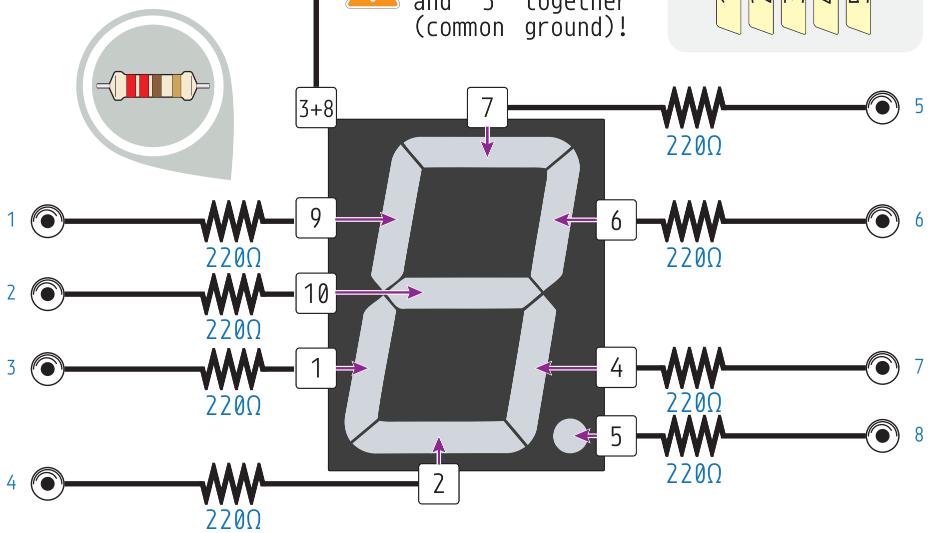
7-Segment Display

Common-Cathode Connections



+5V

Connect pins 8 and 3 together (common ground)!



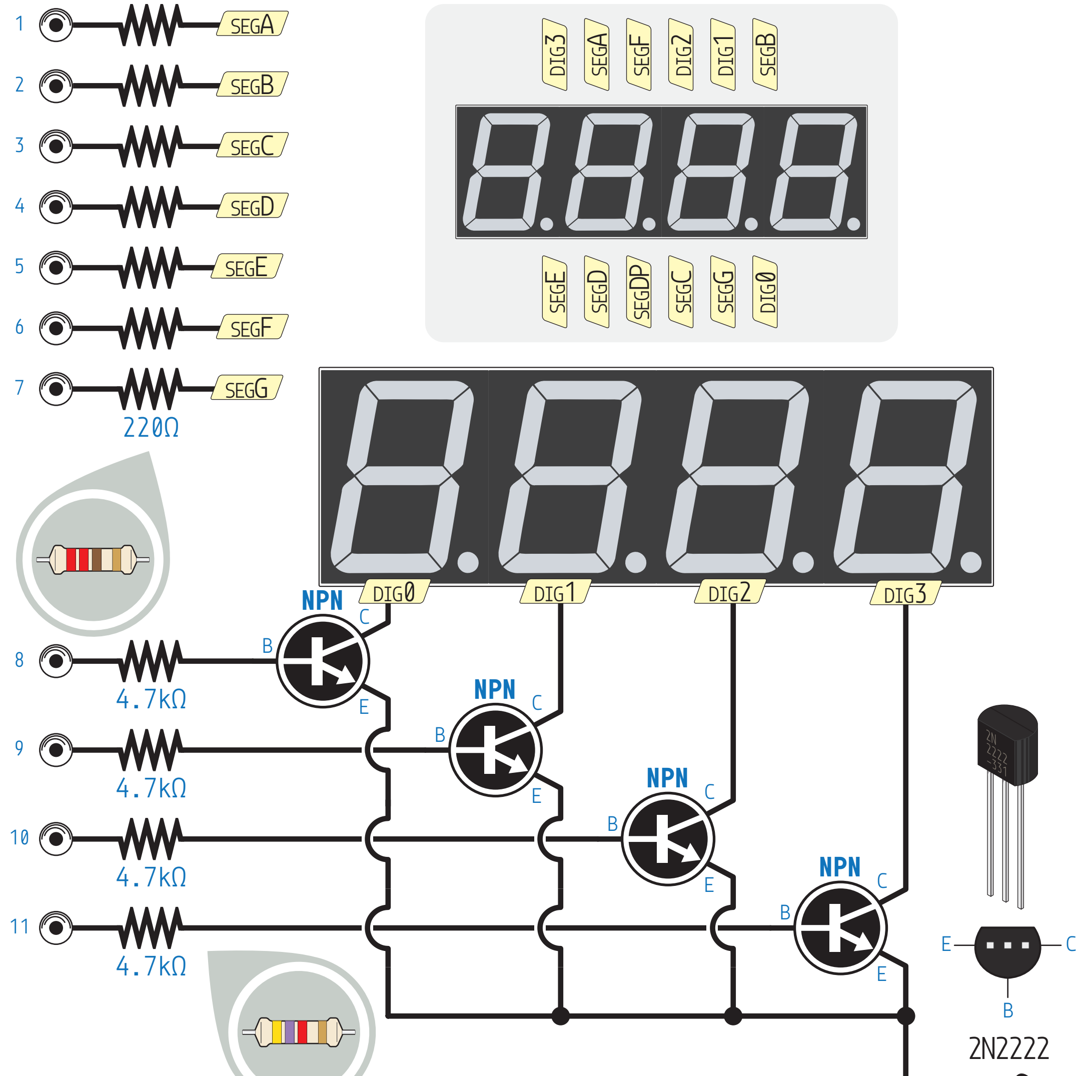
A 7-Segment LED display is an electronic device housing 8 individual LEDs so you should use current-limiting resistors in series with the microcontroller pins. The segments can be combined to produce simplified representations of the arabic numerals or symbols.

18

0-1.es/18

4-Digit 7-Segment Display

Basic Connections



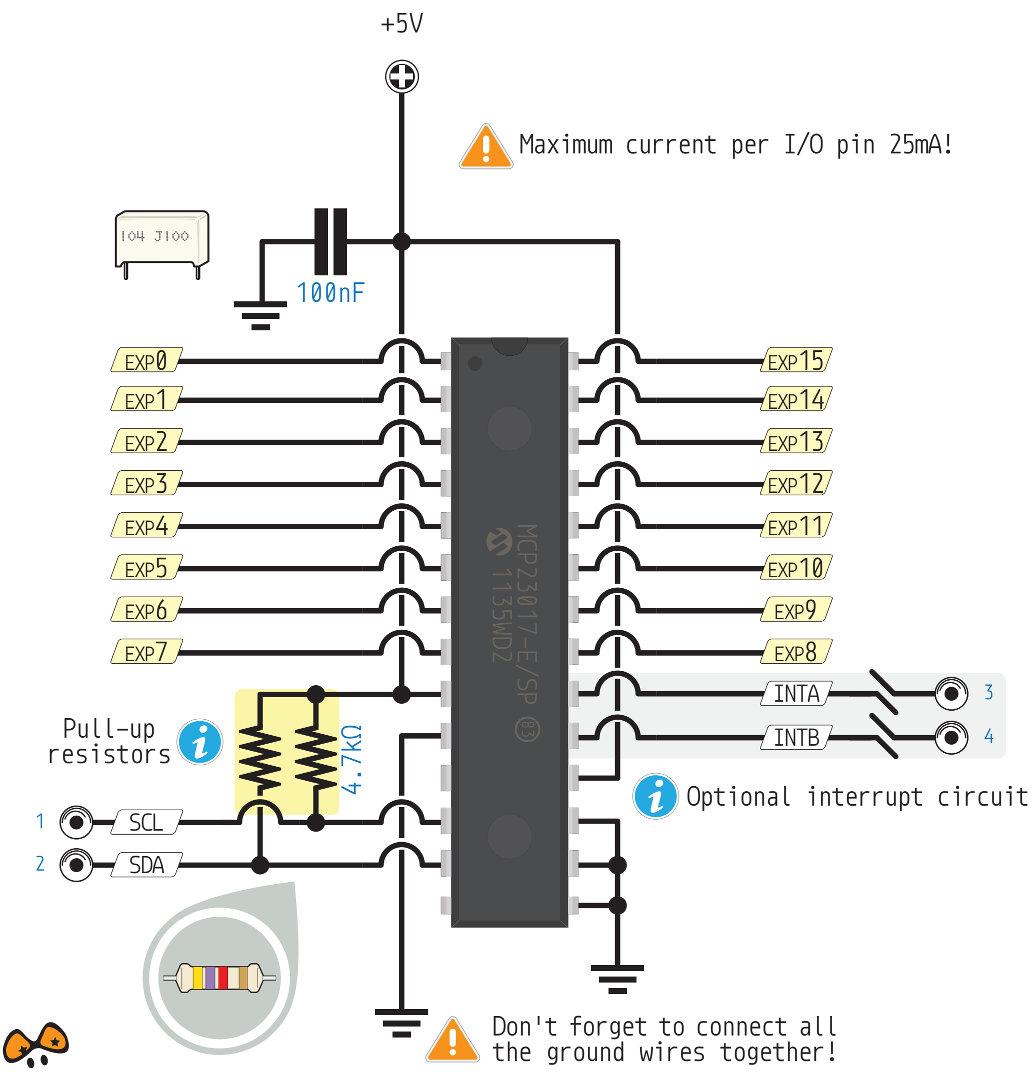
Don't forget to connect all
the ground wires together!

0-1.es/19

19

I/O Expander

Using the MCP23017 I/O Expander

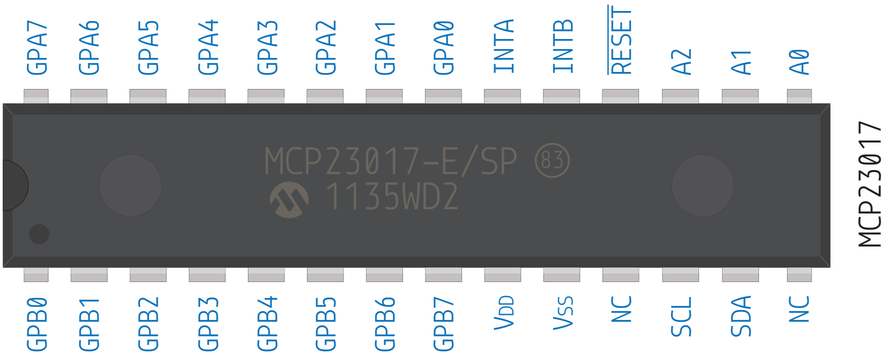


19

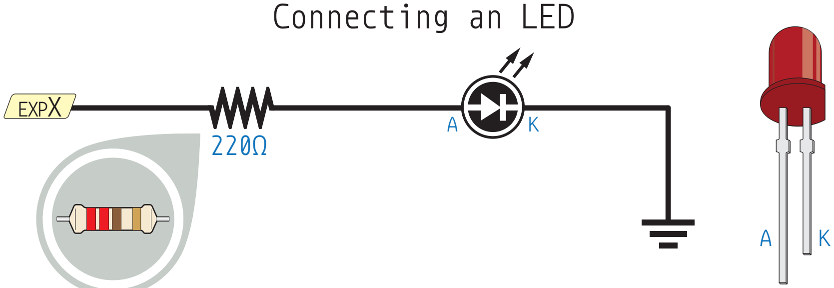
0-1.es/19

MCP23017

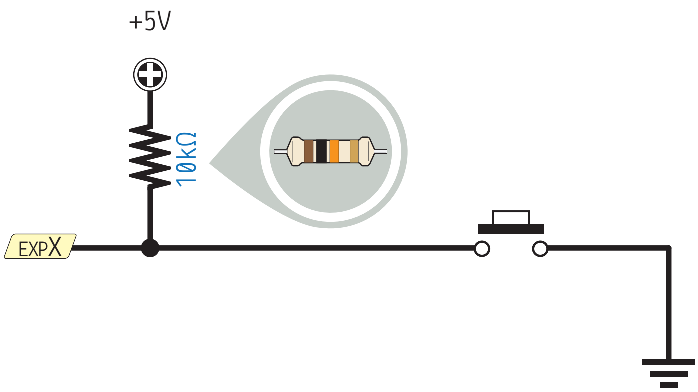
Pinout



Connecting an LED



Connecting a Pushbutton

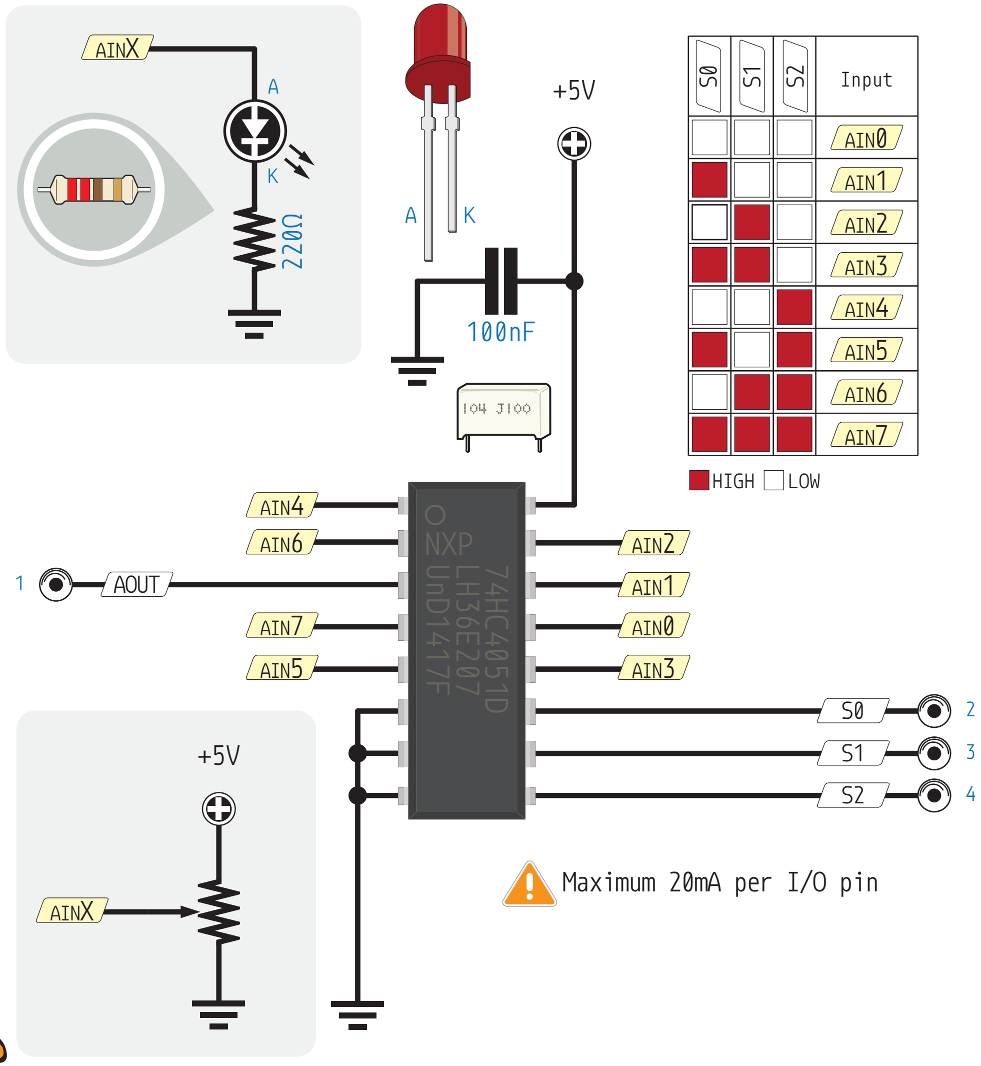


0-1.es/20

20

Analog Mux/Demux

Using the 4051 Mux/Demux



S0	S1	S2	Input
LOW	LOW	LOW	AIN0
HIGH	LOW	LOW	AIN1
LOW	HIGH	LOW	AIN2
HIGH	HIGH	LOW	AIN3
LOW	LOW	HIGH	AIN4
HIGH	LOW	HIGH	AIN5
LOW	HIGH	HIGH	AIN6
HIGH	HIGH	HIGH	AIN7

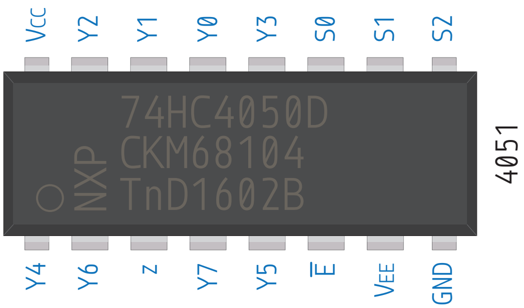
HIGH LOW

Maximum 20mA per I/O pin

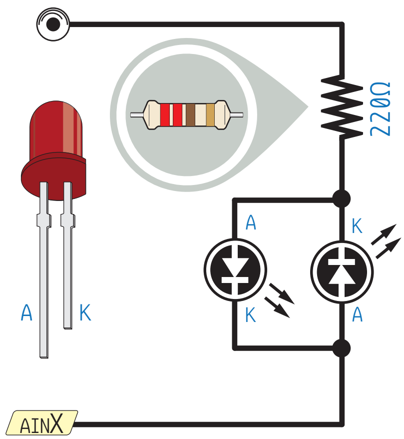
20

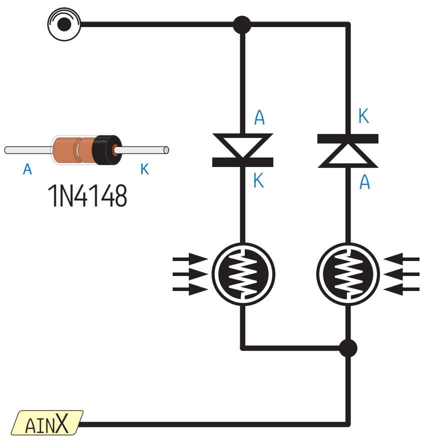
0-1.es/20

4051
Pinout



Doubling the Number of Ports





2
3
4

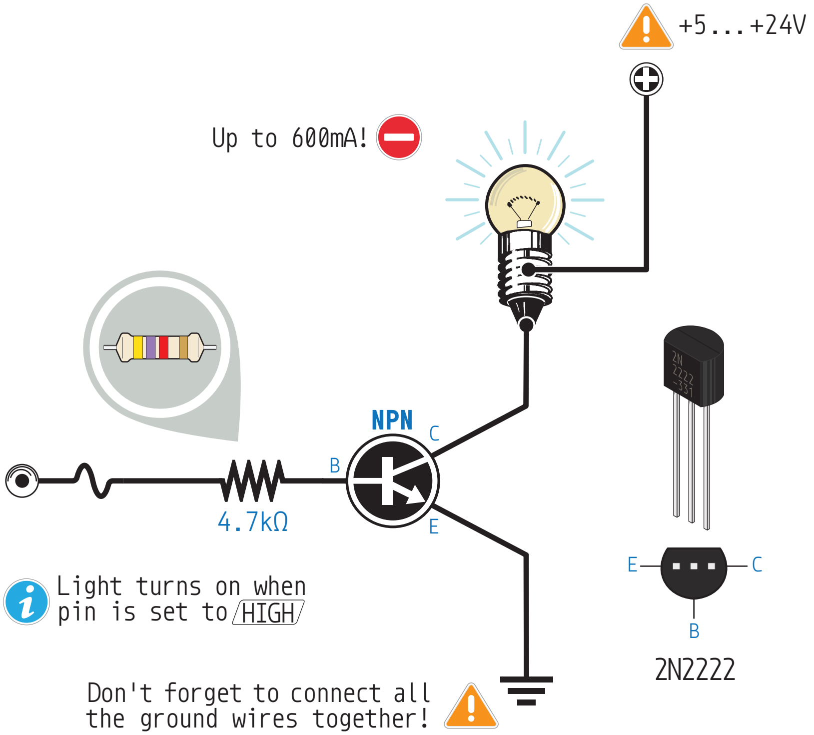
The 4051 is a single-pole octal-throw analog switch suitable for use in analog or digital 8:1 multiplexer/demultiplexer applications. The switch features three digital select inputs, eight independent inputs/outputs and common input/output.

0-1.es/21

21

DC Light Bulb

Low-Power Load



Microcontrollers can only output a very small amount of current from their output pins. These pins are meant to send control signals, not to act as power supplies. The most common way to control a direct current device from a microcontroller is to use a transistor.

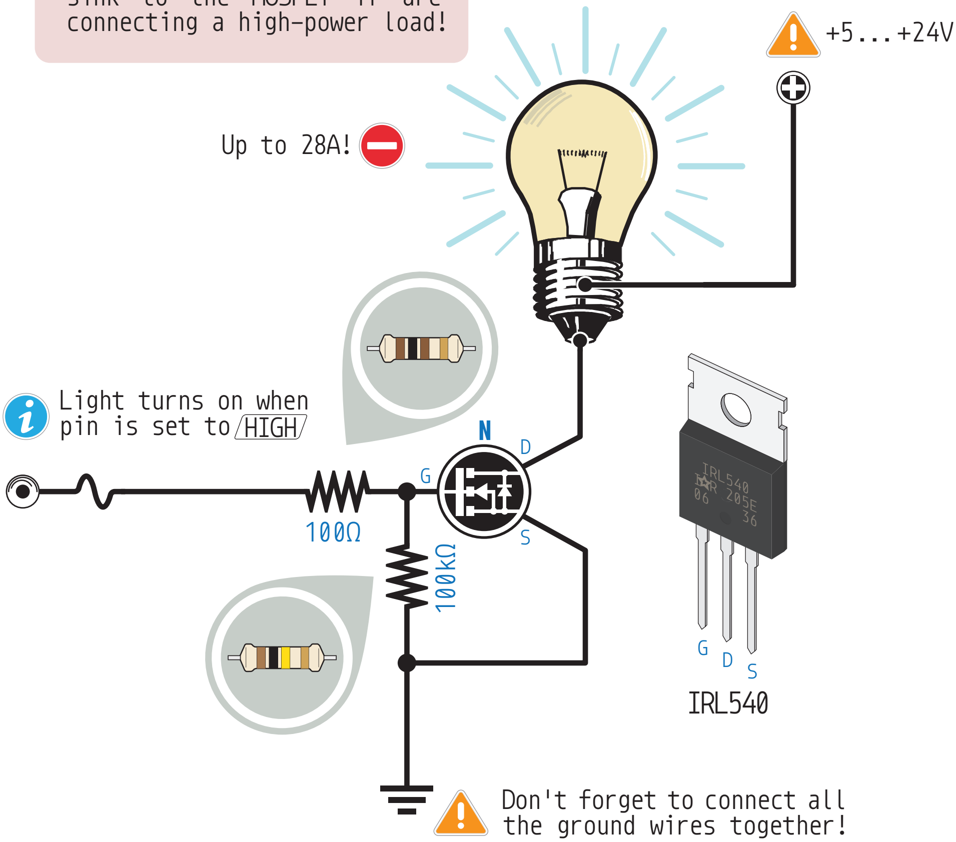
22

0-1.es/22

DC Light Bulb

High-Power Load

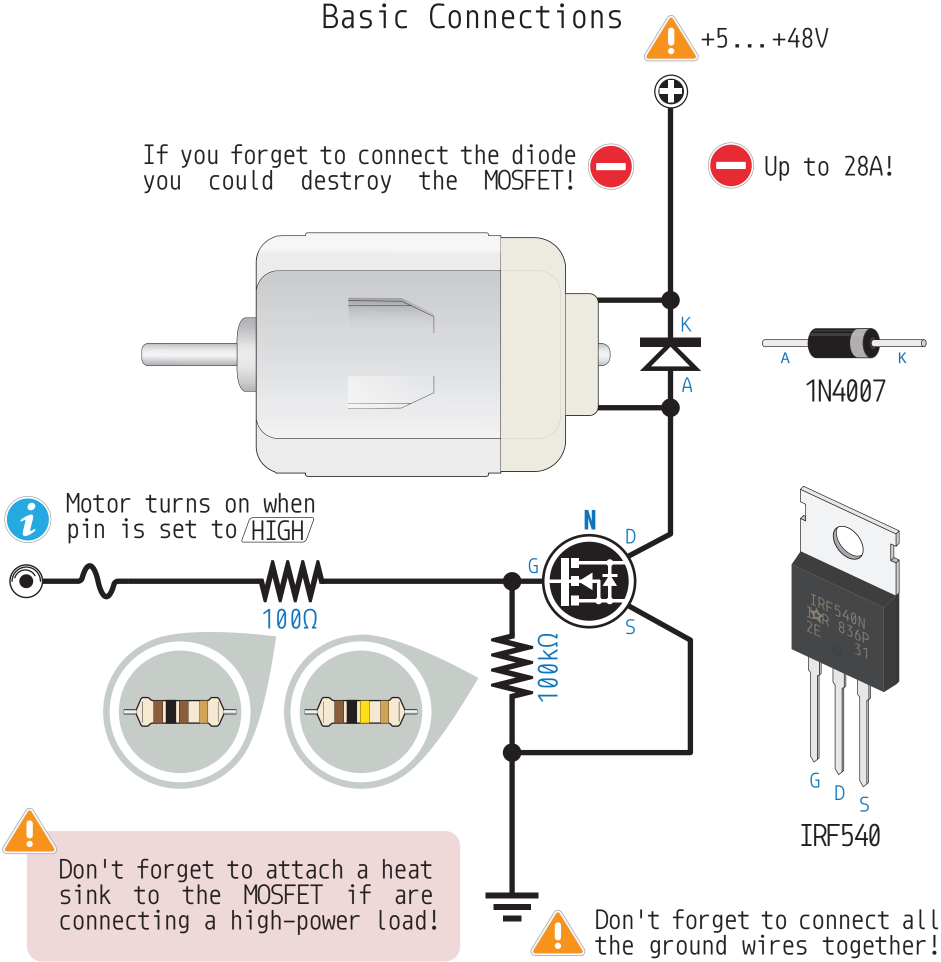
Don't forget to attach a heat sink to the MOSFET if are connecting a high-power load!



The 2N2222 transistor is rated at 800mA maximum, but you should leave a good safety margin. Many electronics projects designed for switching high-current DC loads use MOSFETs. If your lamp is greater than 2W, you need a MOSFET. The IRL540 can deliver its specified 28A continuous current at 5V.

DC Motor

Basic Connections



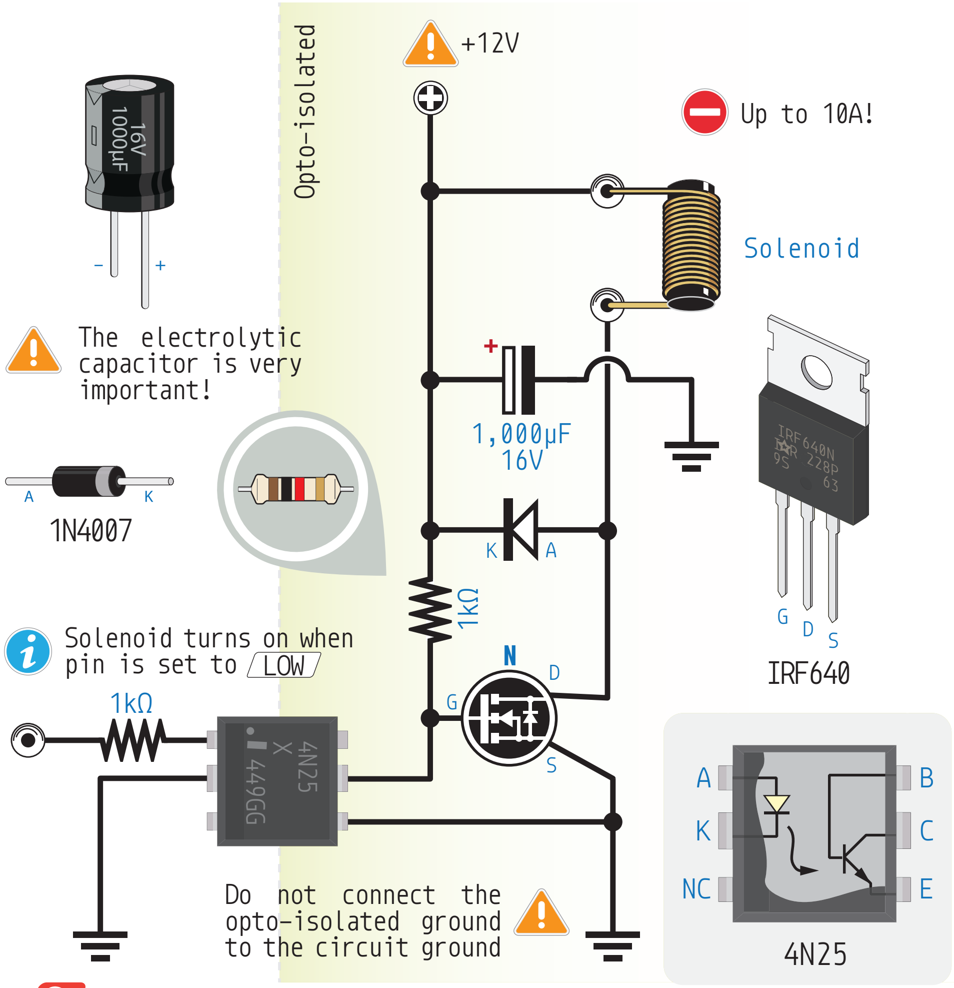
DC motors can create harmful voltage spikes due to their inductive nature. In this schematic the capacitor used for filtering the noise caused by the motor and the diode is used to protect the power supply from reverse voltage caused by the motor acting like an inductor.

24

0-1.es/24

Solenoid

Basic Connections



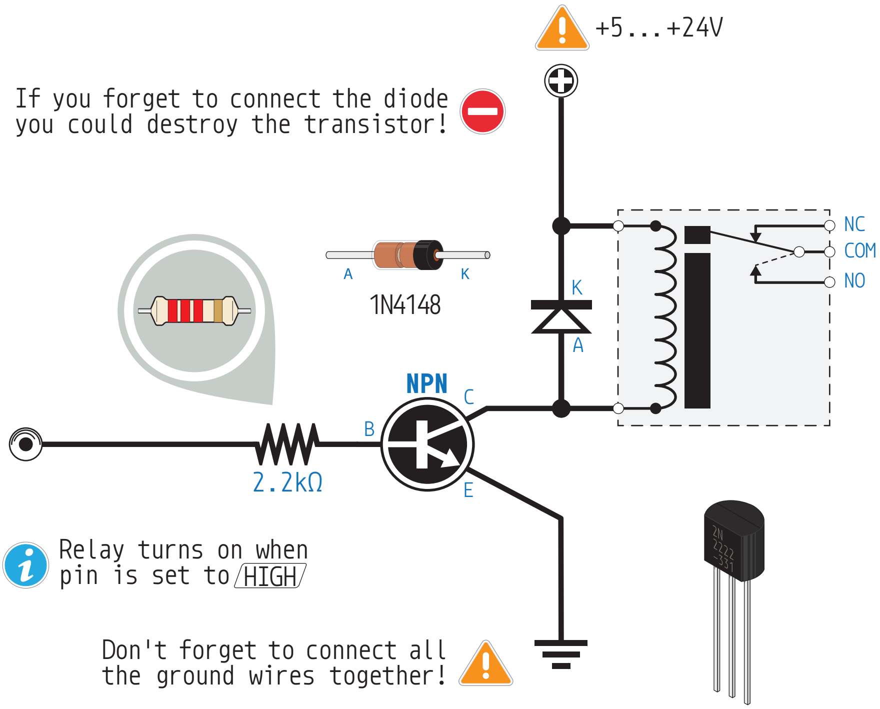
It's very important to use a large electrolytic capacitor in this circuit. The capacitor is used for supplying the current required by solenoid when the circuit is activated.

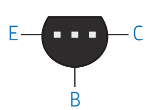
0-1.es/25

25

Relay

Basic Connections





2N2222

Relays have two types of contacts: NO and NC. NO stands for “Normally Open”, whereas NC stands for “Normally Closed”. When the relay is turned off, NO contacts are open and NC contacts are closed. On the other hand, when the relay is turned on, NO contacts are closed and NC contacts are open.

25

0-1.es/25

Relay
Test Code

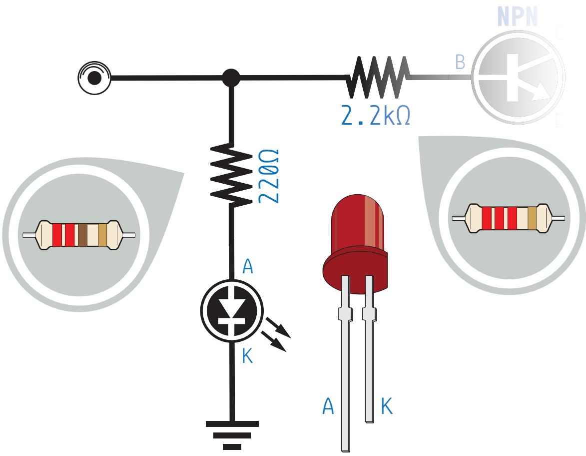
```
int relayPin = 9;

void setup() {
        pinMode(relayPin,OUTPUT);
}

void loop() {
        digitalWrite(relayPin,HIGH);
        delay(3000);
        digitalWrite(relayPin,LOW);
        delay(3000);
}
```

Assign variable *relayPin* as pin 9

Initialize the pin as an OUTPUT

Turn the relay ON
Wait for 3 seconds
Turn the relay OFF
Wait for 3 seconds

Status LED for the Relay



Relays offer complete isolation between the control circuit and the load. They can switch AC and DC and they can be very reliable and robust. Compared to transistors, relays are very slow. Relays are ON-OFF devices, whereas transistors can have their voltage drop varied.

0-1.es/26

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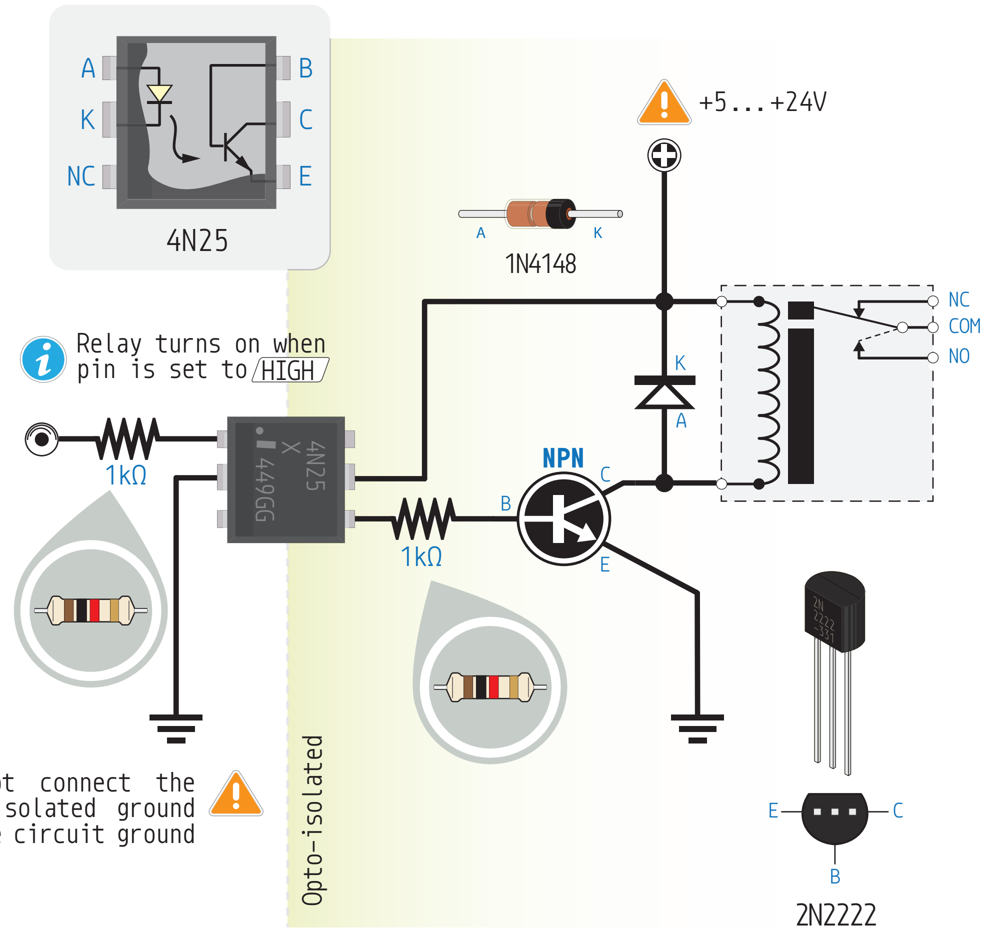
Opto-Isolated Relay

Basic Connections



Relay turns on when pin is set to /HIGH/

Do not connect the opto-isolated ground to the circuit ground

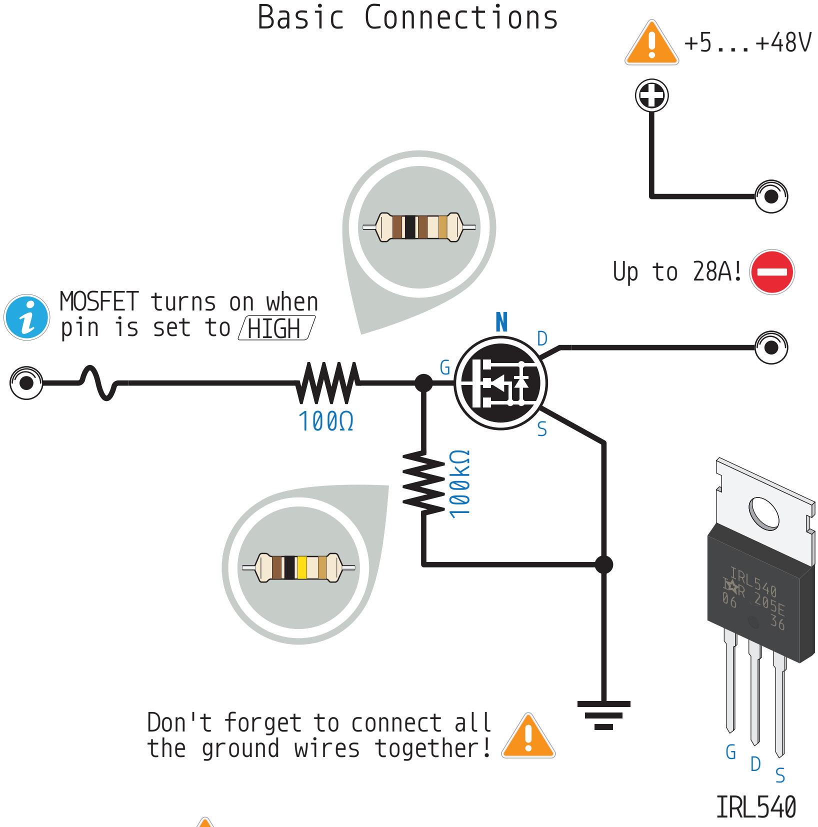
The purpose of an optocoupler is to isolate two parts of a circuit. Typical examples are industrial units with lots of interferences which affect the signals in the wires. If these interferences are not isolated, they can affect the correct functioning of the unit and cause errors.

27

0-1.es/27

Logic-Level MOSFET

Basic Connections



Don't forget to attach a heat sink to the MOSFET if are connecting a high-power load!

If you need to switch high-current and/or high-voltage loads with a microcontroller board, you need to use a MOSFET. This circuit is reccomended only for switching purposes or in low frequency applications. The IRL540 can deliver its specified 28A continuous current at 5V.

0-1.es/28

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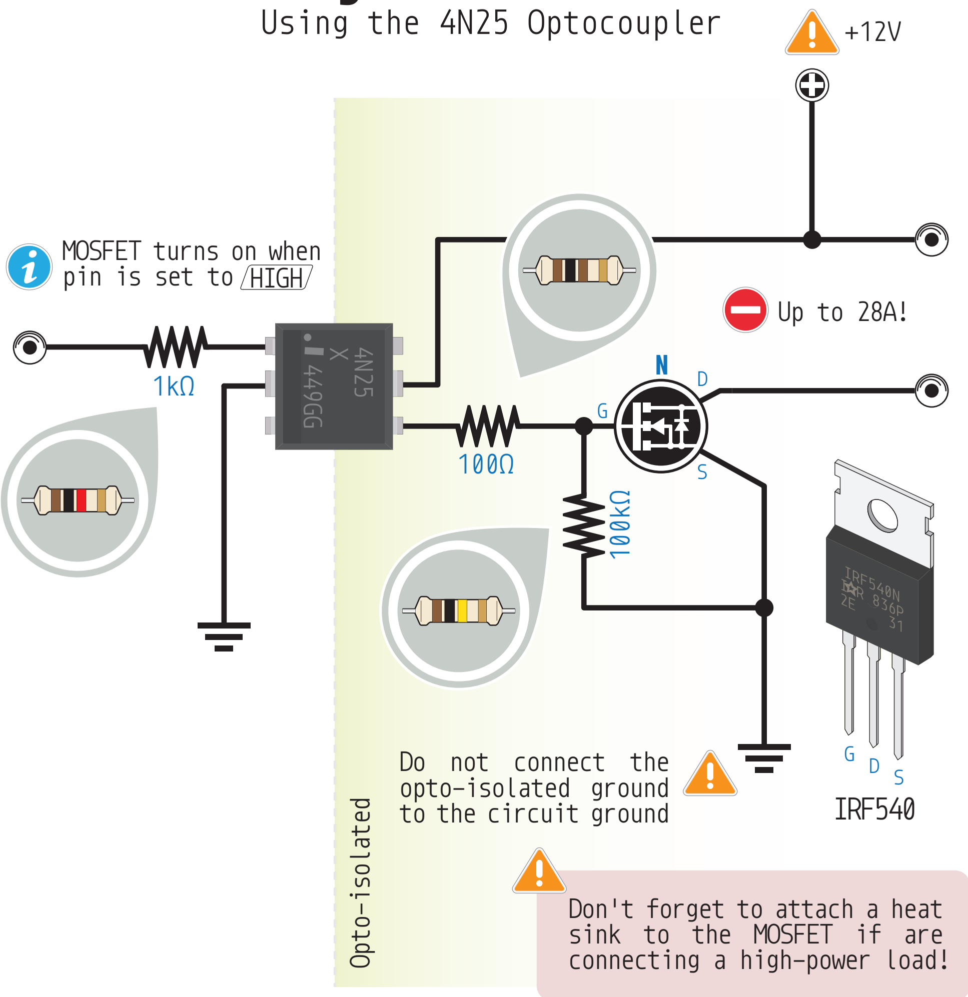
Non-Logic-Level MOSFET

Using the 4N25 Optocoupler



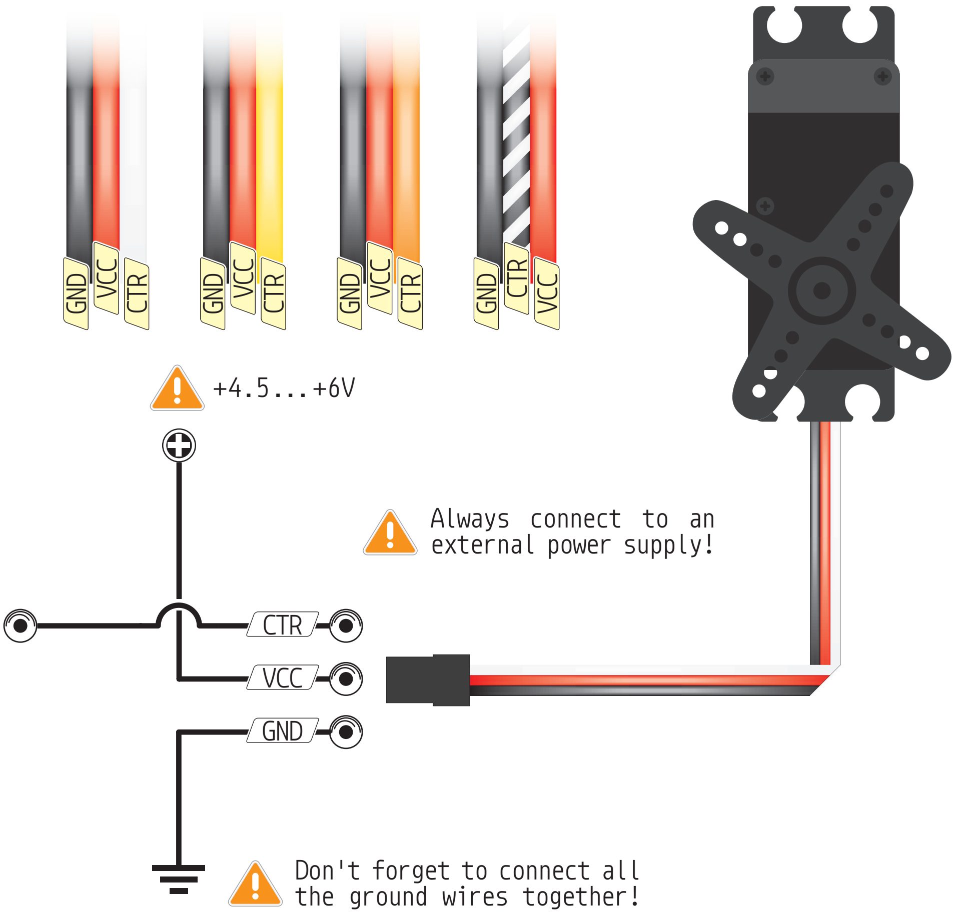
Use this circuit if you have a power FET (like the IRF series) and need some galvanic separation from your microcontroller circuit. This circuit is reccomended only for switching purposes or in low frequency applications. The IRF540 can deliver its specified 28A of continuous current at 10V.

29

0-1.es/29

Servo

Basic Connections



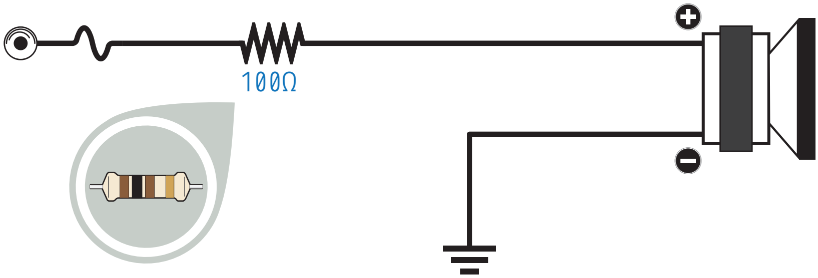
Standard servos are designed to receive electronic signals that tell them what position to hold. They are used, for example, to control the position of flaps, rudders and steering. Continuous rotation servos on the other hand turn at certain speed and direction. They are useful for driving wheels and pulleys.

0-1.es/30

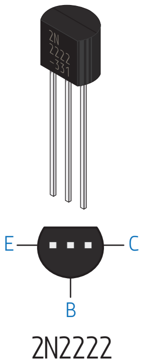
30

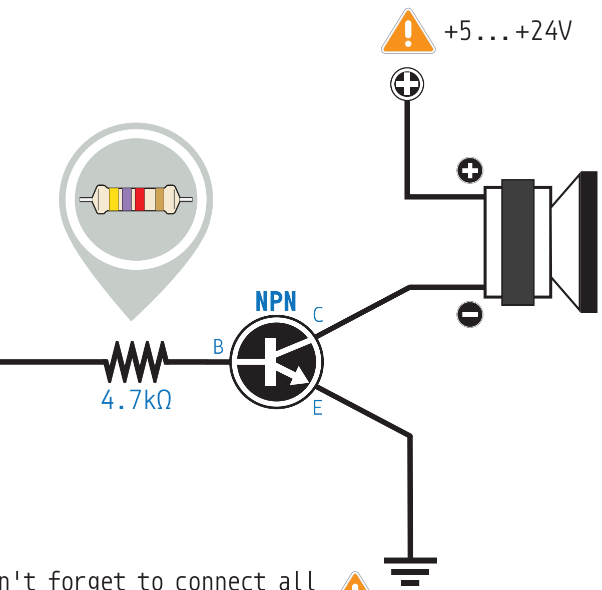
Magnetic Buzzer

Basic Connections



With External Power Supply





Don't forget to connect all
the ground wires together!

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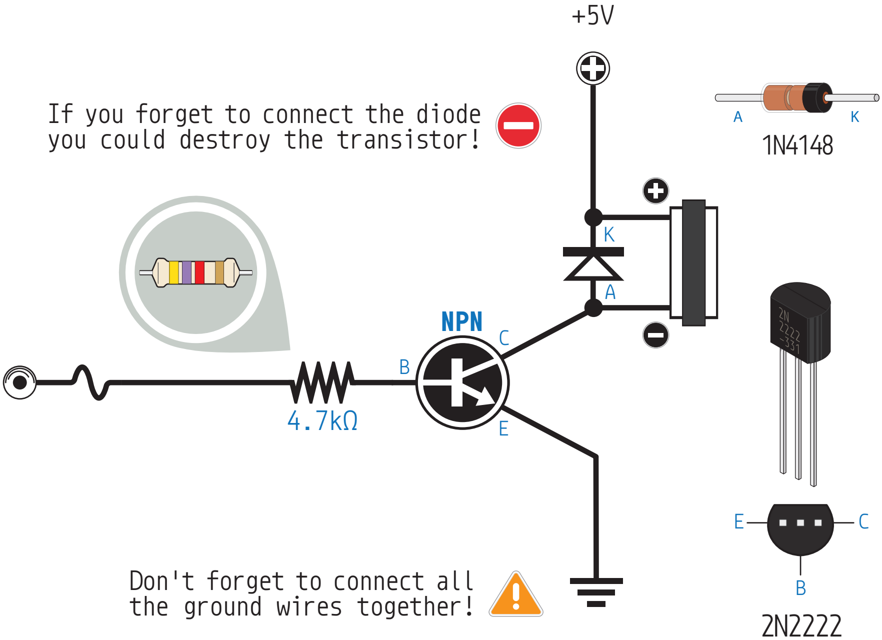
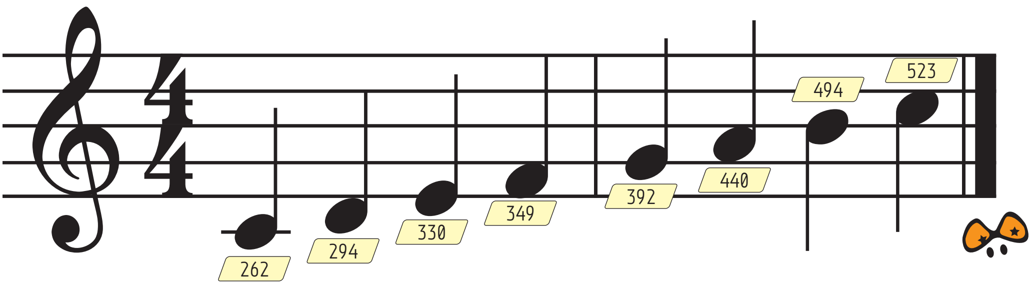
0-1.es/31

Piezo Buzzer

Basic Connections



Note Frequency (Hz)



0-1.es/32

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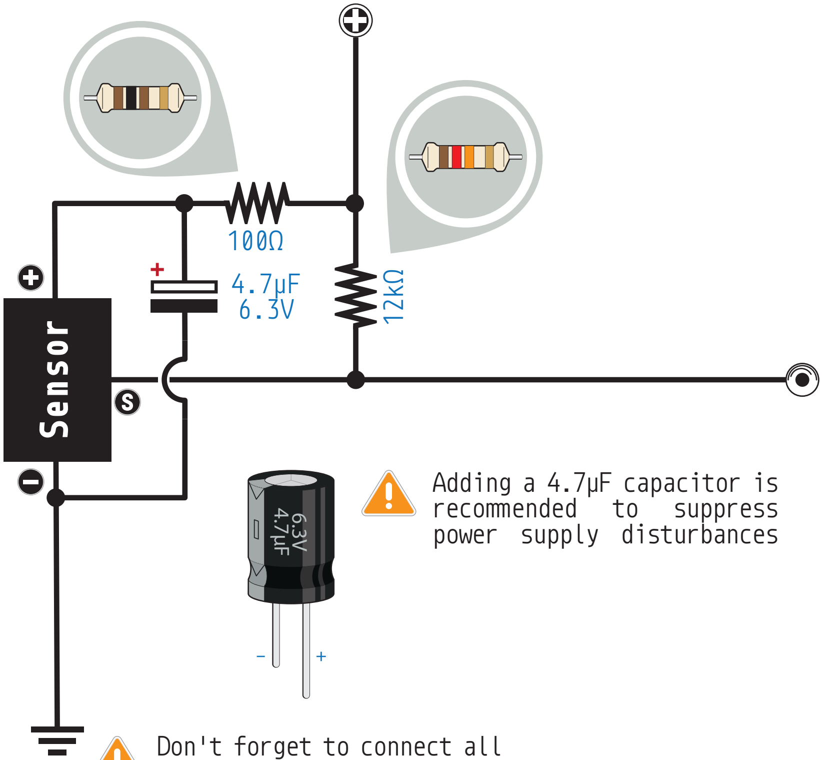
IR Detector

Basic Connections



Adding a 4.7µF capacitor is recommended to suppress power supply disturbances

Don't forget to connect all the ground wires together!

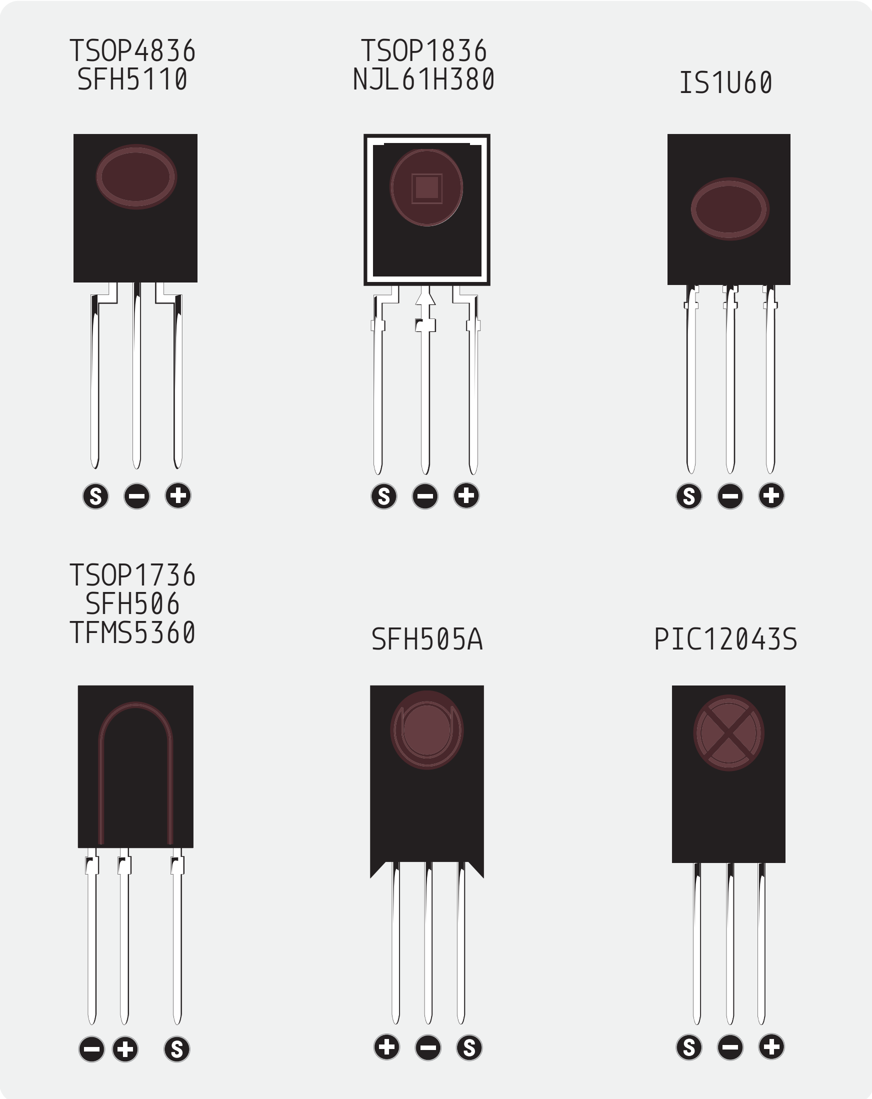
IR detectors are tiny microchips with a photocell that are tuned to detect infrared light. They are almost always used for remote control detection. IR detectors are digital out, either they detect a signal over a carrier (usually 38kHz) and output LOW (0V) or they do not detect anything and output HIGH (5V).

32

0-1.es/32

IR Detector

Common IR Detectors



0-1.es/33

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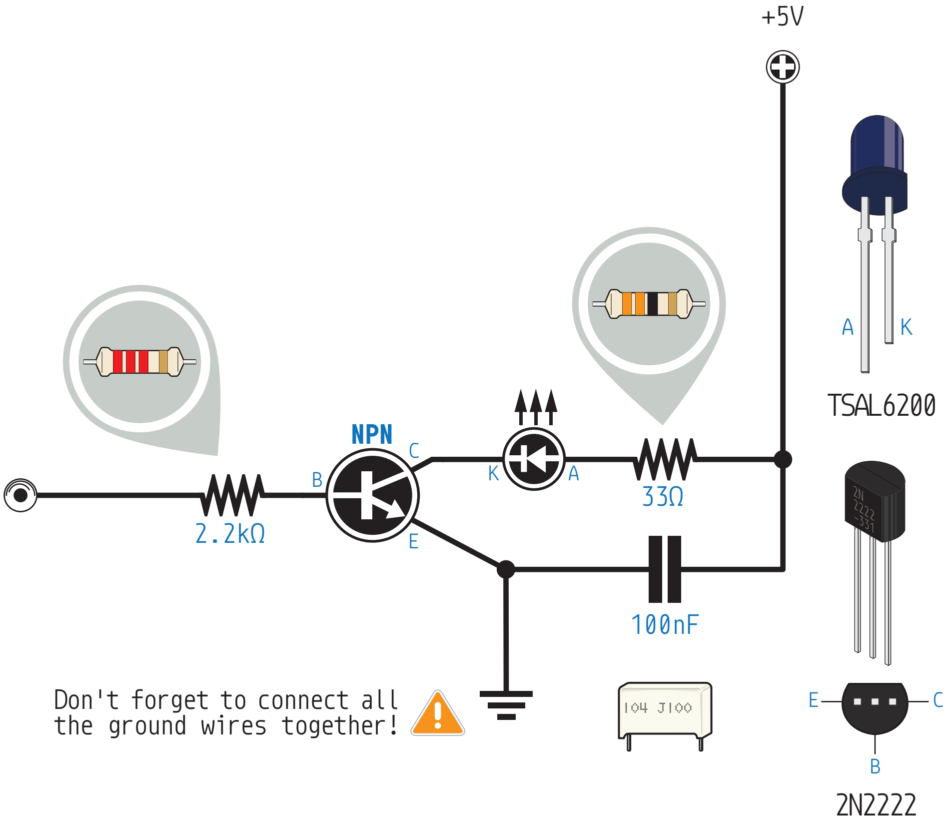
IR Emitter

Basic Connections



Don't forget to connect all the ground wires together!

IR (infrared) comunication is a popular, inexpensive, and easy to use wireless comunication technology. IR light is very similar to visible light, except that it has a slightly longer wavelength. This means IR is undetectable to the human eye, making it perfect for wireless comunication.

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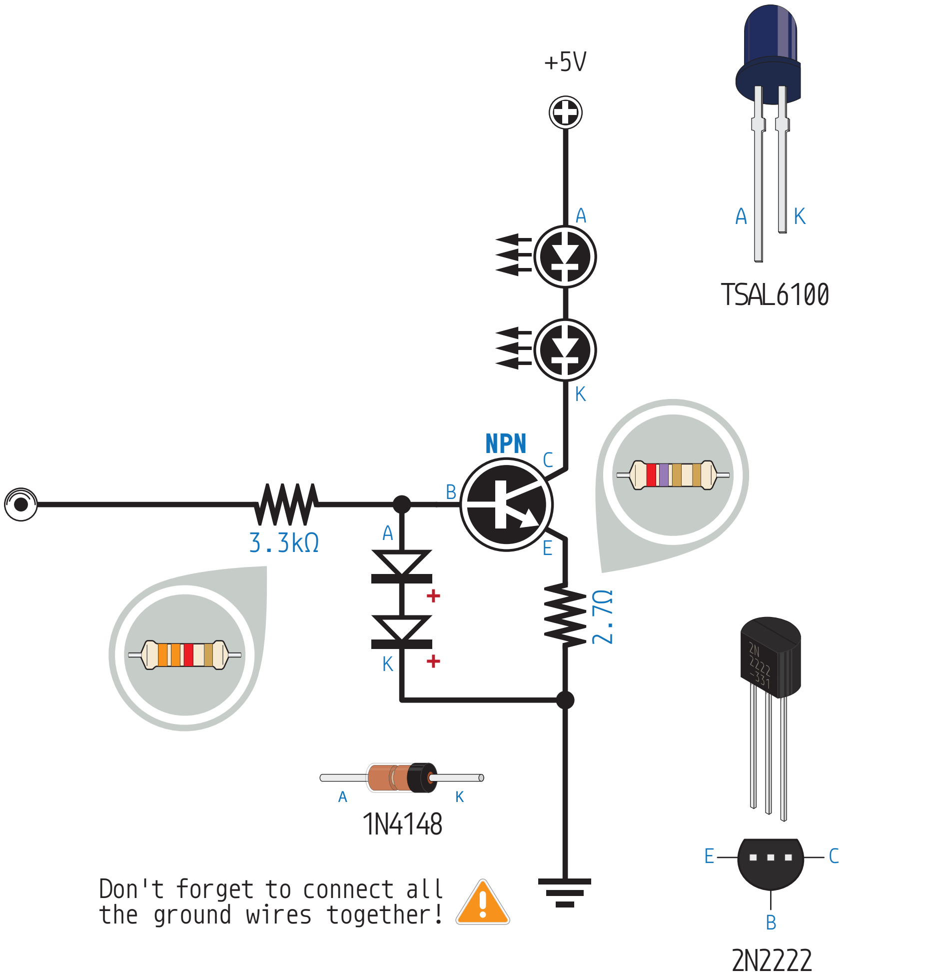
0-1.es/34

Constant-Current IR Emitter

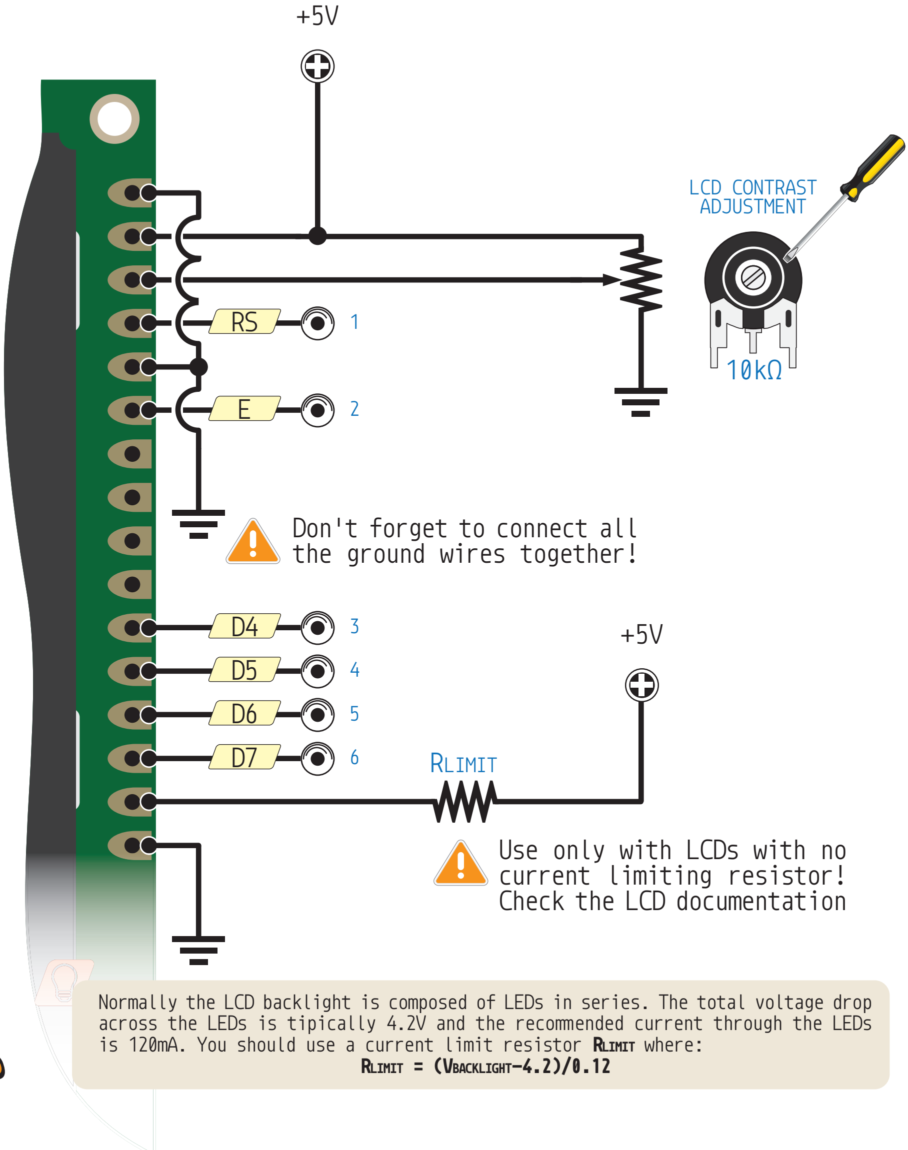
Basic Connections



Don't forget to connect all the ground wires together!

HD44780-Based LCD

Basic Connections



Don't forget to connect all the ground wires together!

Use only with LCDs with no current limiting resistor! Check the LCD documentation

Normally the LCD backlight is composed of LEDs in series. The total voltage drop across the LEDs is tipically 4.2V and the recommended current through the LEDs is 120mA. You should use a current limit resistor **R_{LIMIT}** where:

$$R_{LIMIT} = (V_{BACKLIGHT} - 4.2)/0.12$$

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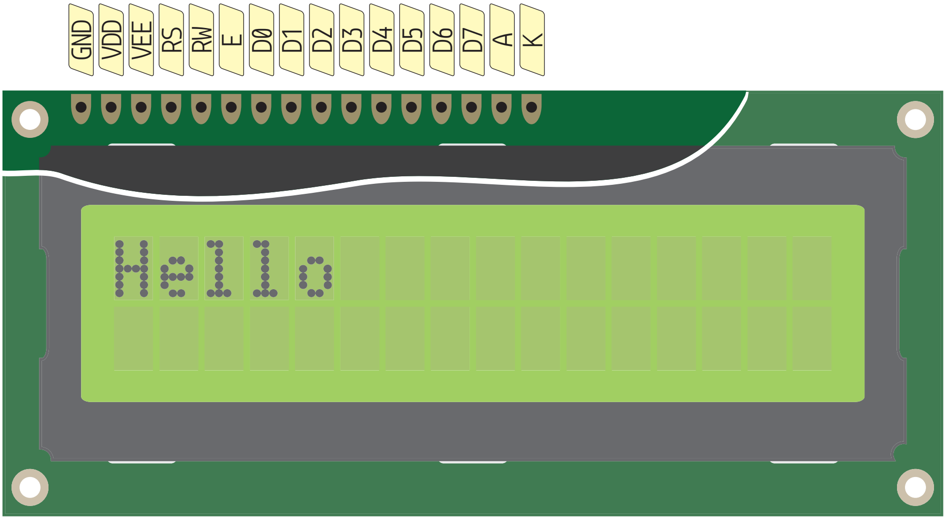
0-1.es/35

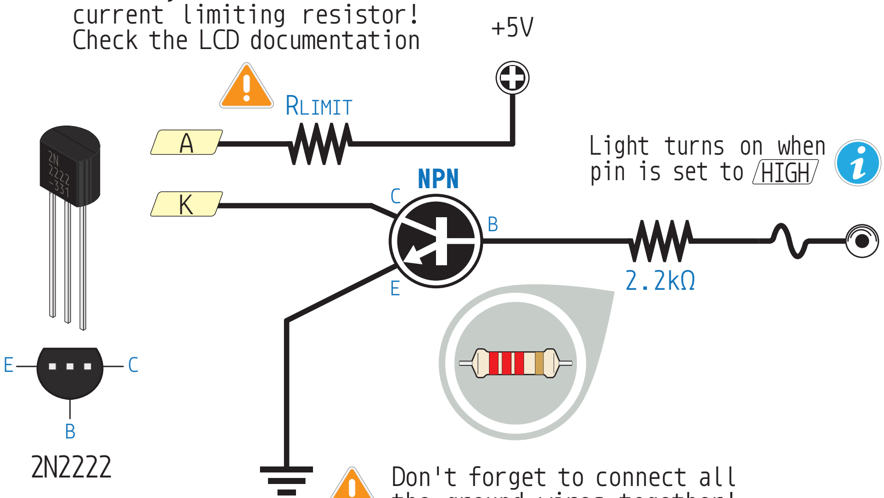
HD44780-Based LCD

Pinout



LCD Backlight Control

Use only with LCDs with no current limiting resistor! Check the LCD documentation



Don't forget to connect all the ground wires together!

0-1.es/36

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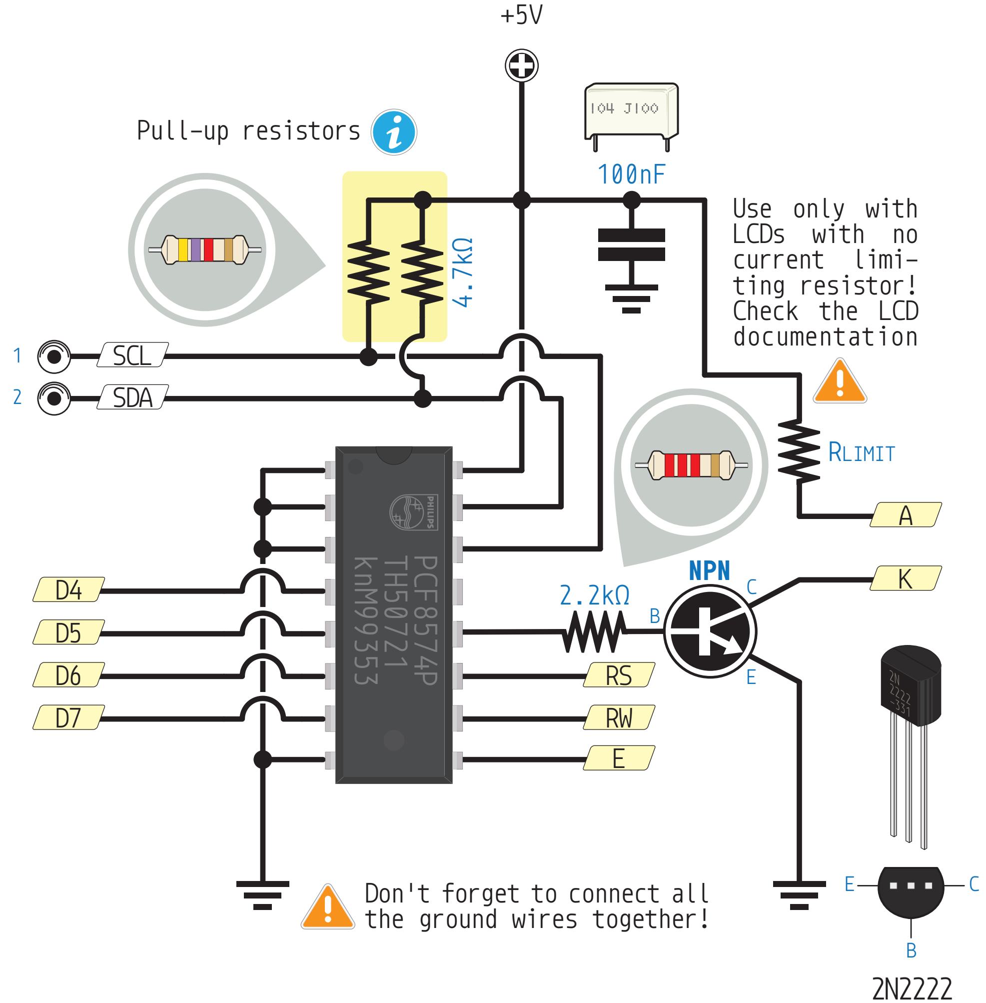
HD44780-Based LCD Via I²C

Using the PCF8574 I/O Expander



Don't forget to connect all the ground wires together!

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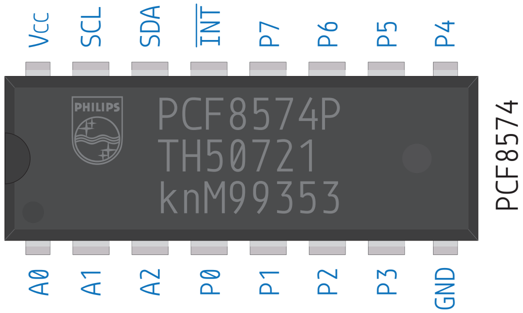
0-1.es/36

PCF8574
Pinout



I²C Pull-Up Resistors

I²C is a popular communication protocol in embedded systems. When interfacing with the slave device a pull-up resistor is needed on each bi-directional line. This is just two wires, called SCL and SDA. SCL is the clock line that is used to synchronize all data transfers over the I²C bus. SDA is the data line. The SCL and SDA lines are connected to all devices on the I²C bus. There needs to be a third wire which is just the ground. Both SCL and SDA lines are *"open drain"* drivers. What this means is that the chip can drive its output low, but it cannot drive it high. For the line to be able to go high you must provide pull-up resistors to the 5V supply. There should be a resistor from the SCL line to the 5V line and another from the SDA line to the 5V line. You only need one set of pull-up resistors for the whole I²C bus, not for each device.

0-1.es/37

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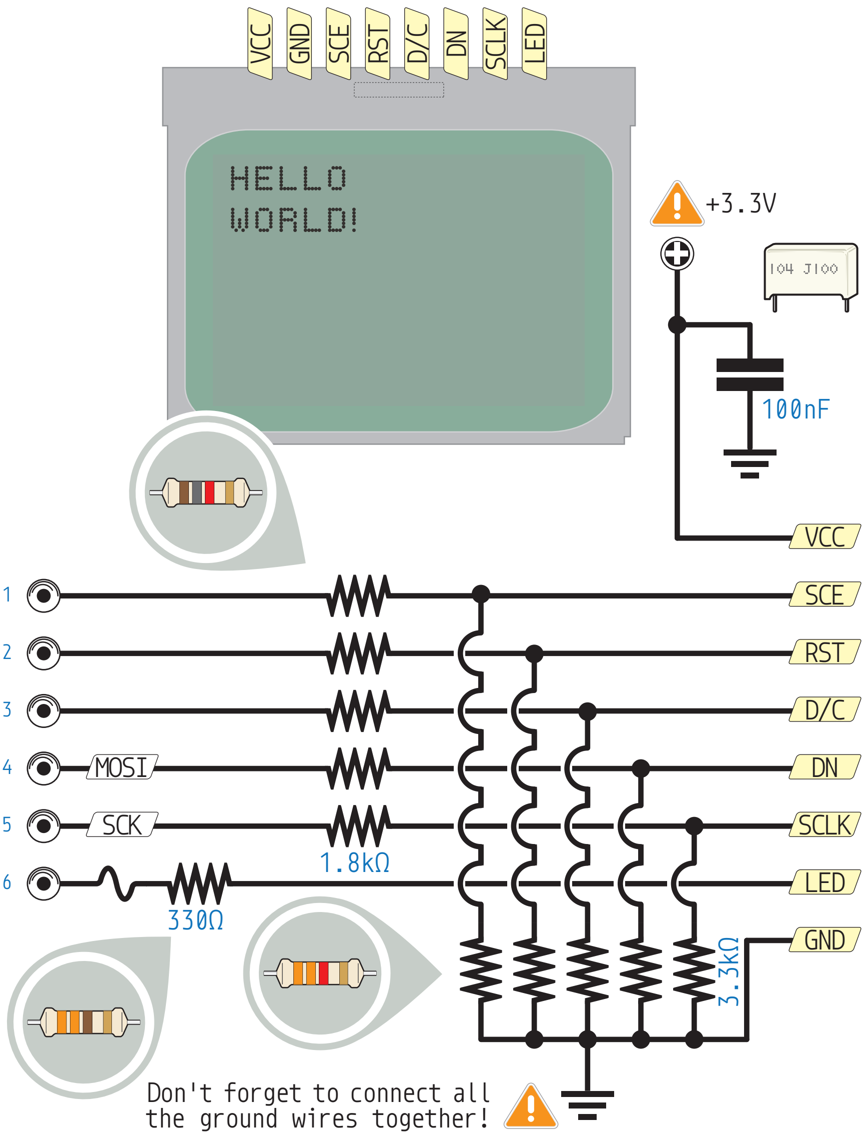
Nokia 5110 LCD

Basic Connections



Don't forget to connect all the ground wires together!

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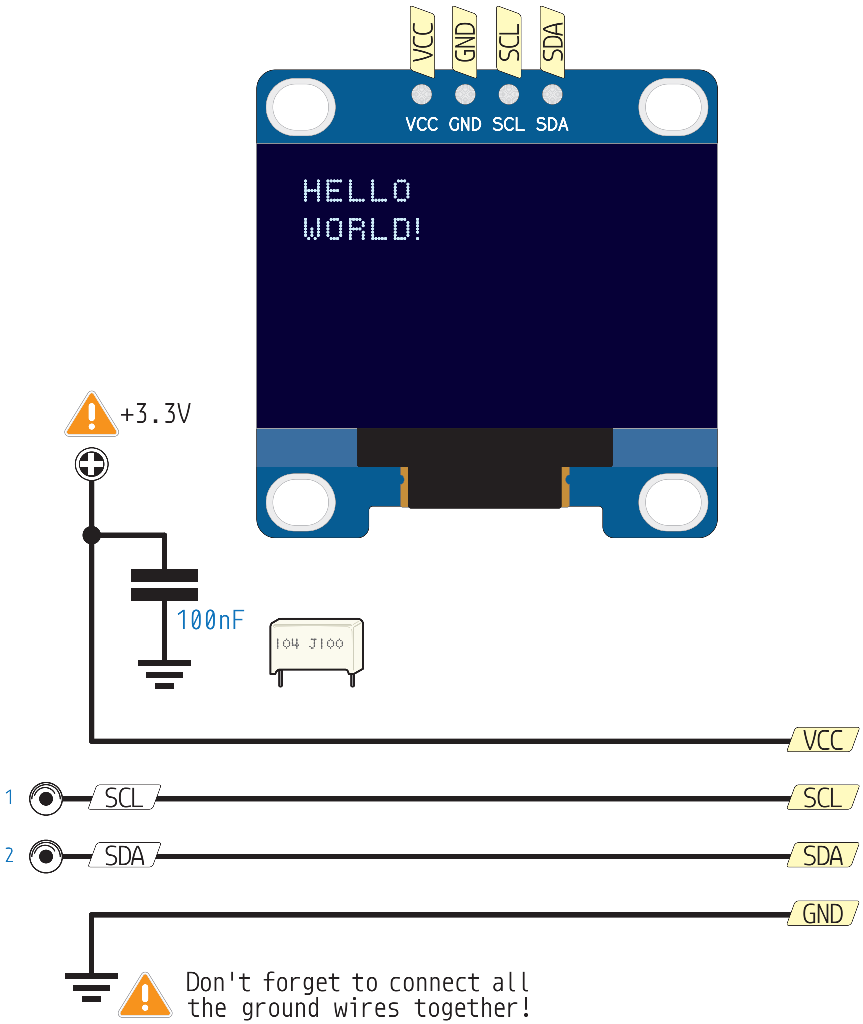
0-1.es/38

OLED LCD

Basic Connections



0-1.es/39

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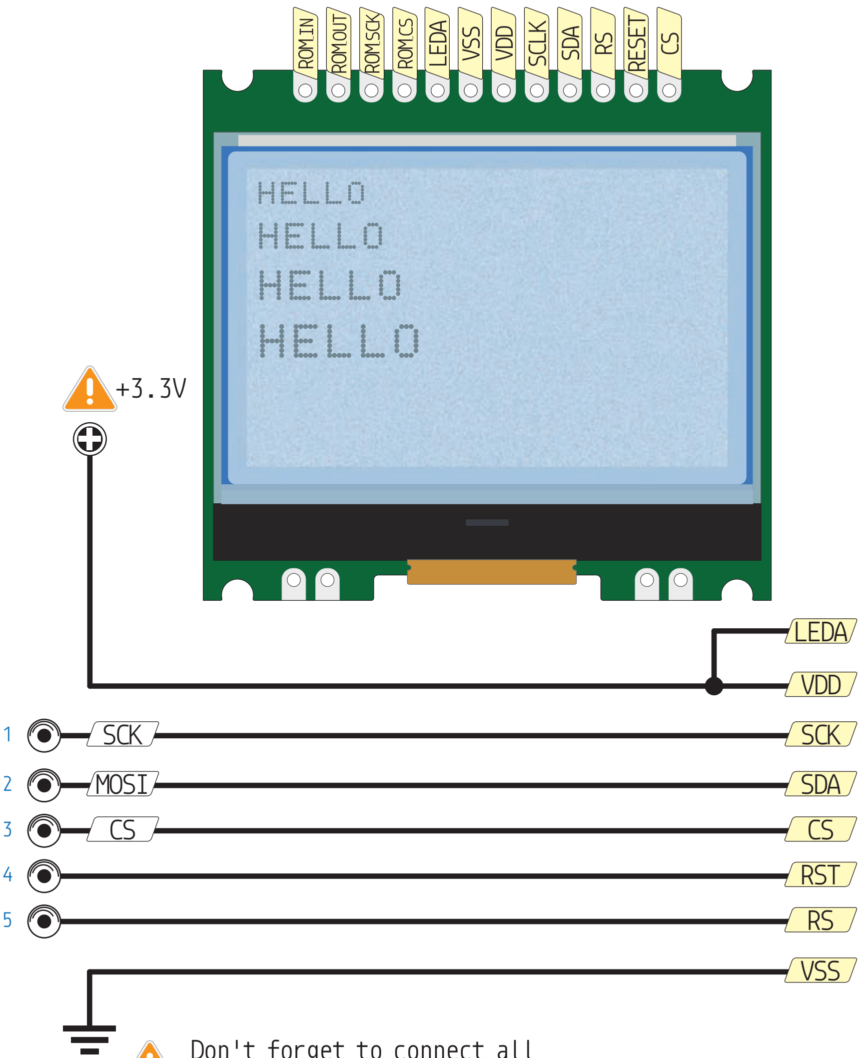
UC1701 128x64 LCD

Basic Connections



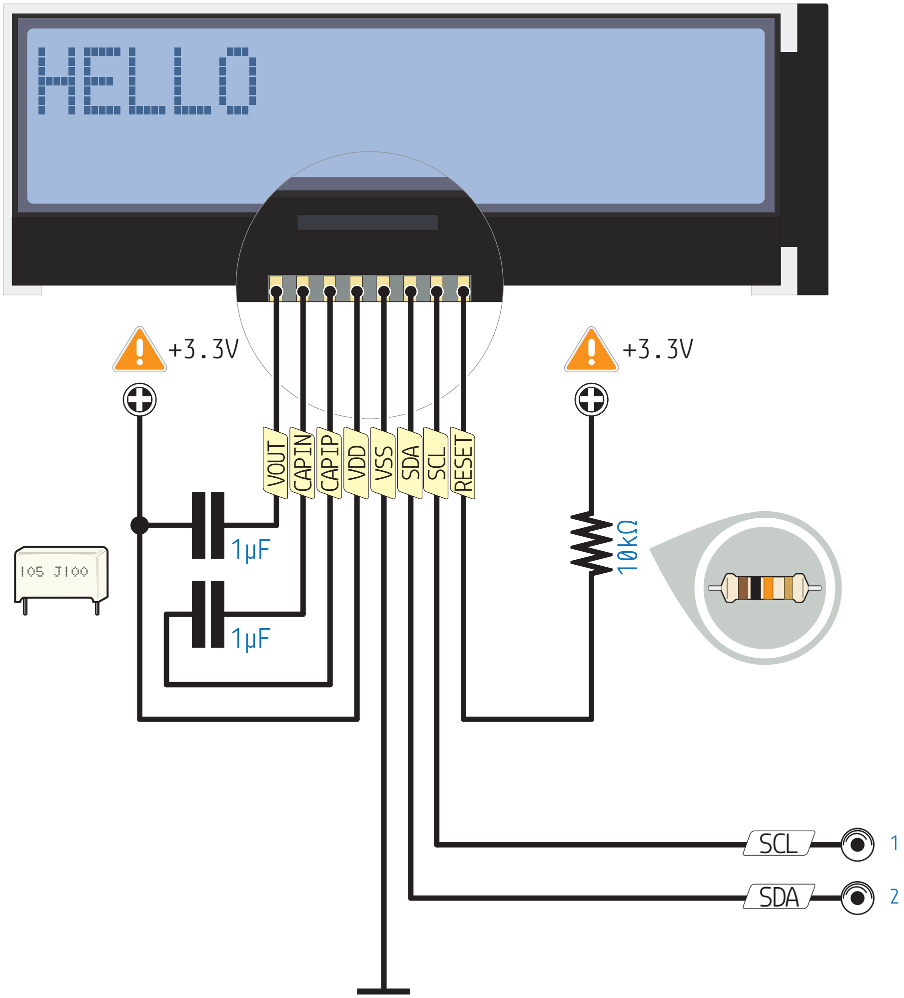
Don't forget to connect all
the ground wires together!

40

0-1.es/40

ST7032i LCD

Basic Connections



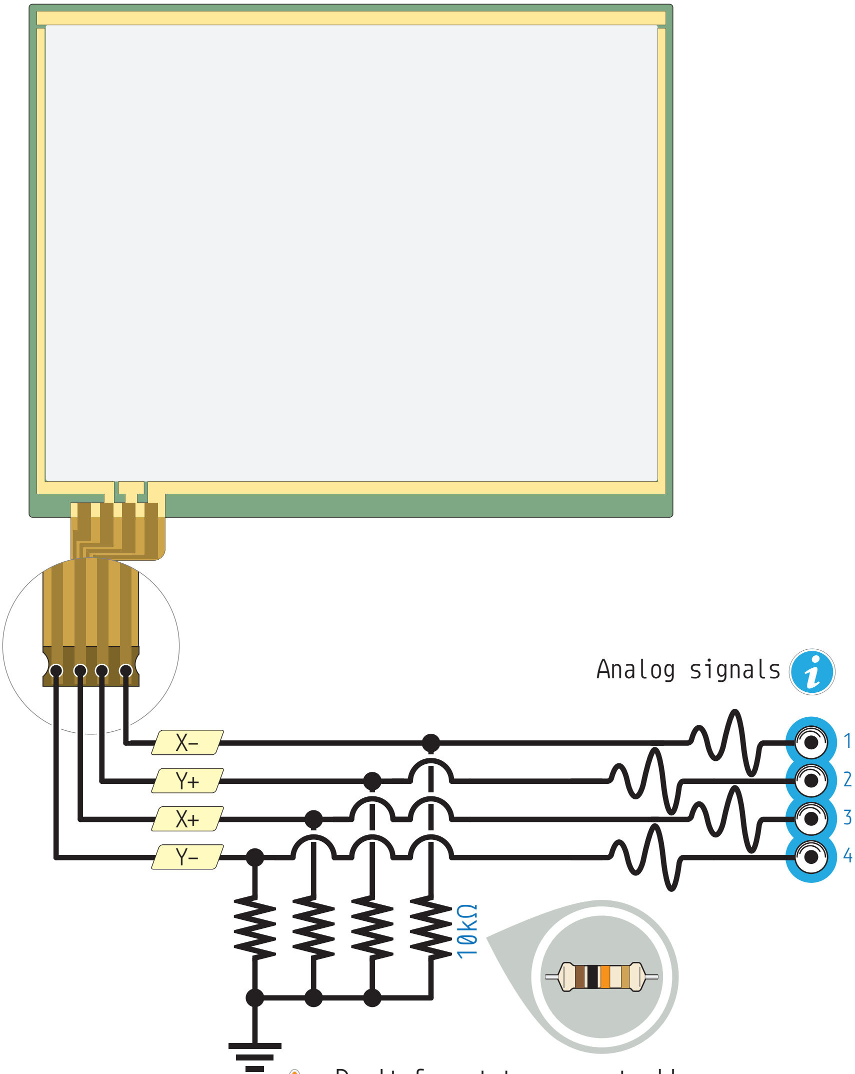
Don't forget to connect all the ground wires together!

0-1.es/41

41

DS Touchscreen

Basic Connections



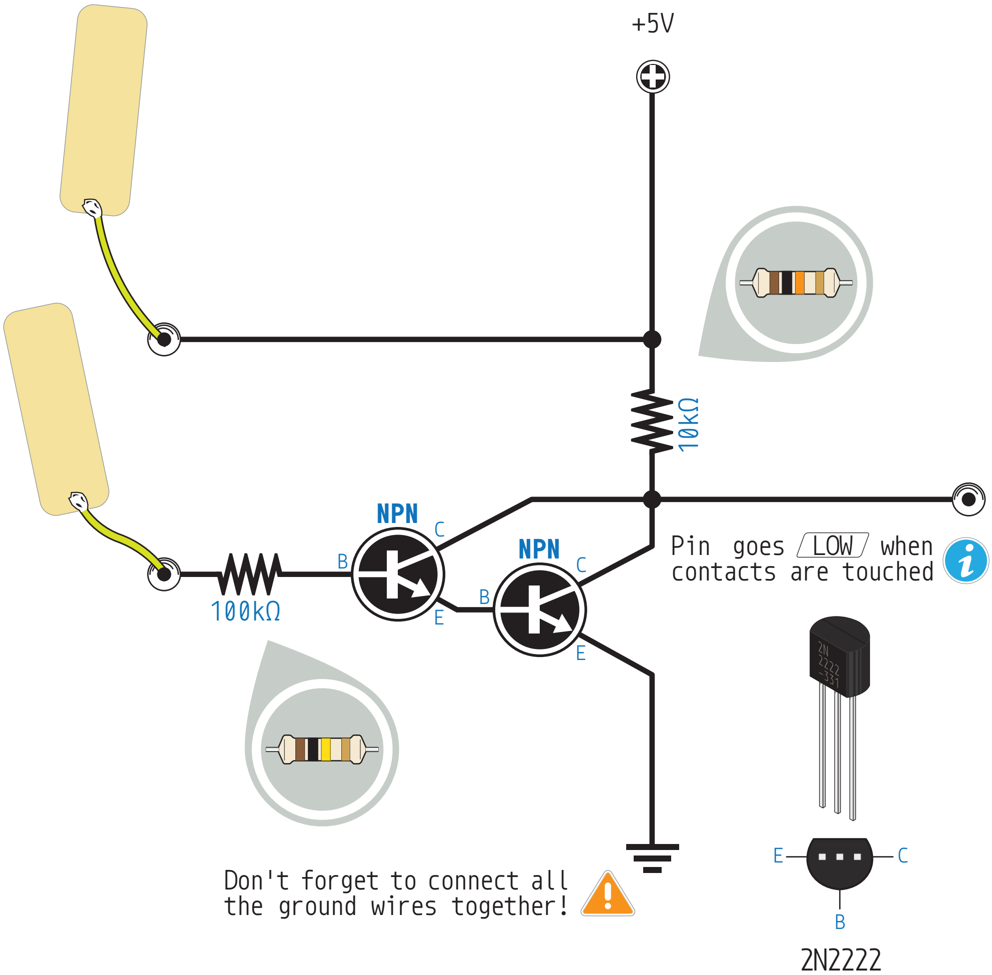
Don't forget to connect all the ground wires together!

42

0-1.es/42

Simple Touch Sensor

Basic Connections



This simpe touch sensor is based on a Darlington configuration of transistors. They behave like a single transistor with a very high current gain, making it sensitive enough to respond to the small current passing through your body when you touch the metallic plates, activating the circuit.

0-1.es/43

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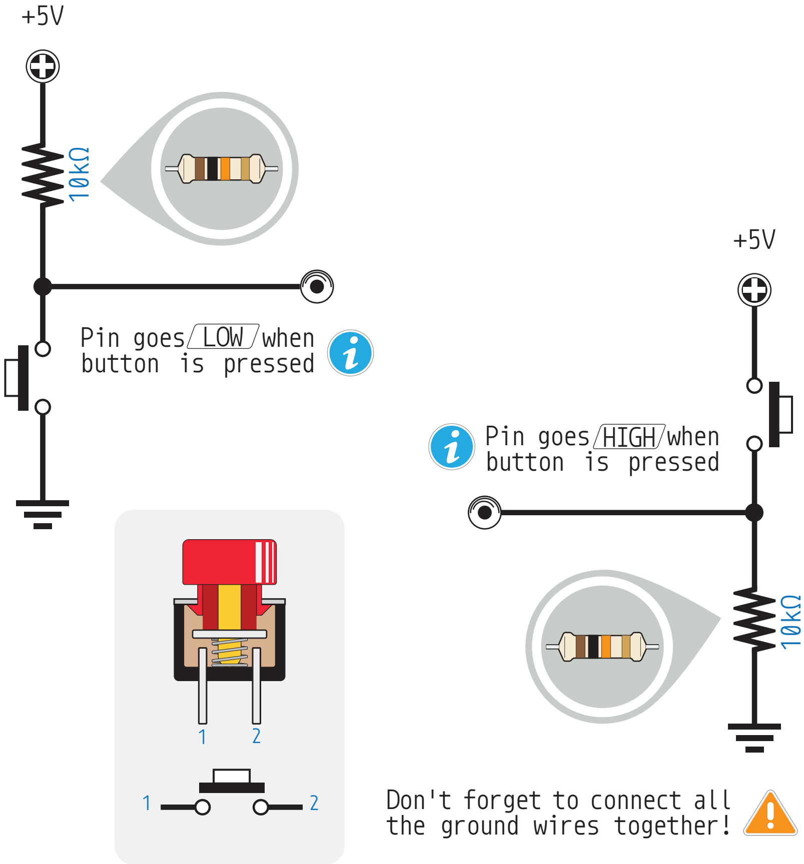
Pushbutton

Basic Connections



Pushbuttons or switches connect two points in a circuit when you press them. If you don't use the pull-up or pull-down resistor, the input pin is “floating” and will randomly return either HIGH or LOW values. Don’t forget to connect all the ground wires together!

43

0-1.es/43

Pushbutton

Test Code

```
int LEDPin = 13;
int SWITCHPin = 4;
int val;

void setup() {
      pinMode(LEDPin,OUTPUT);
      pinMode(BUTTONPin,INPUT);
}

void loop() {
      val = digitalRead(SWITCHPin);
      if (val == LOW) {
            digitalWrite(LEDPin,HIGH);
      }
      if (val == HIGH) {
            digitalWrite(LEDPin,LOW);
      }
}
```

Assign variable *LEDPin* as pin 13
Assign variable *SWITCHPin* as pin 4
Variable for reading the pin status

Initialize the pin as an *OUTPUT*
Initialize the pin as an *INPUT*

Read input value and store it in *val*
Check if the button is pressed
Turn LED on

Check if the button is not pressed
Turn LED off

Using Internal Pull-Up Resistors

Pin goes HIGH when button is pressed

Don't forget to connect all the ground wires together!

0-1.es/44

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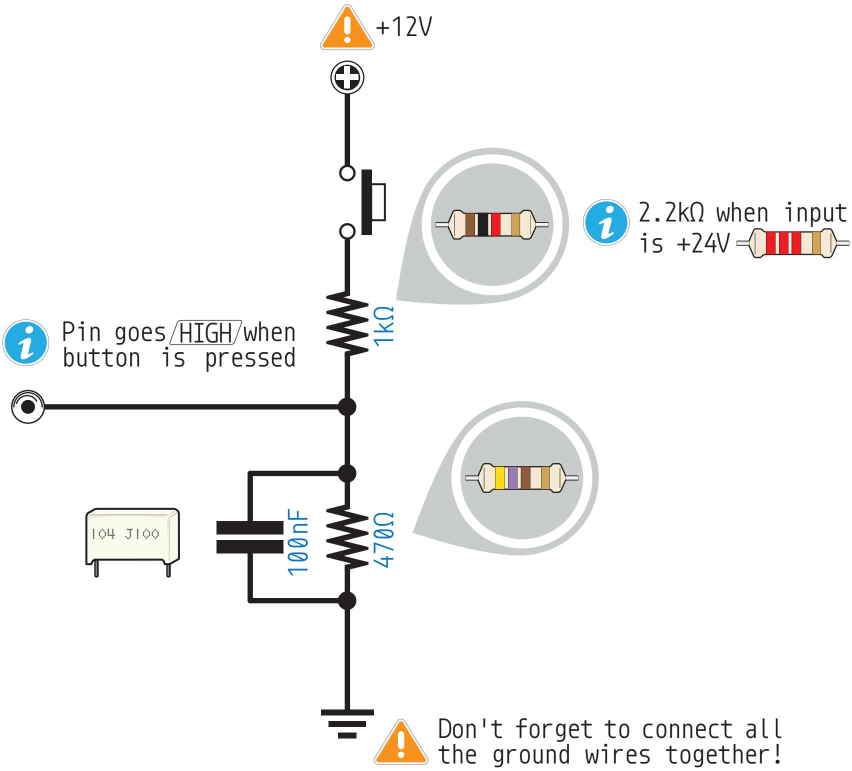
Pushbutton to 12V

Basic Connections



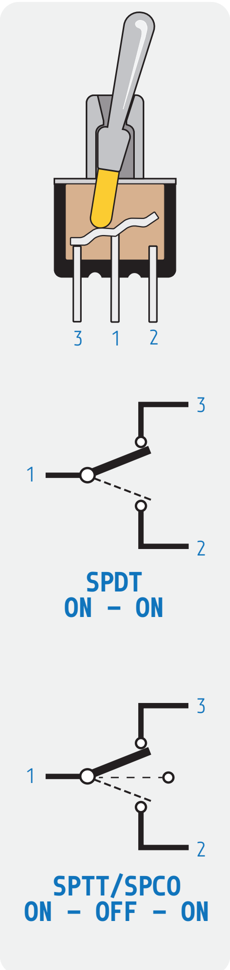
12V signals are often found in many electronic systems and appliances, as signal voltage swings of 12V are advantageous to increase noise immunity. Electronic noise captured by the input wiring will be reduced by about 2/3 thanks to the resistor divider. Noise can be further reduced by the 100nF capacitor.

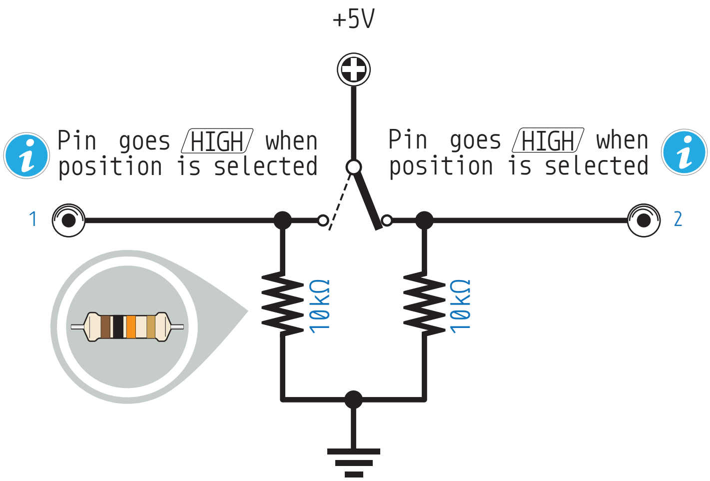
45

0-1.es/45

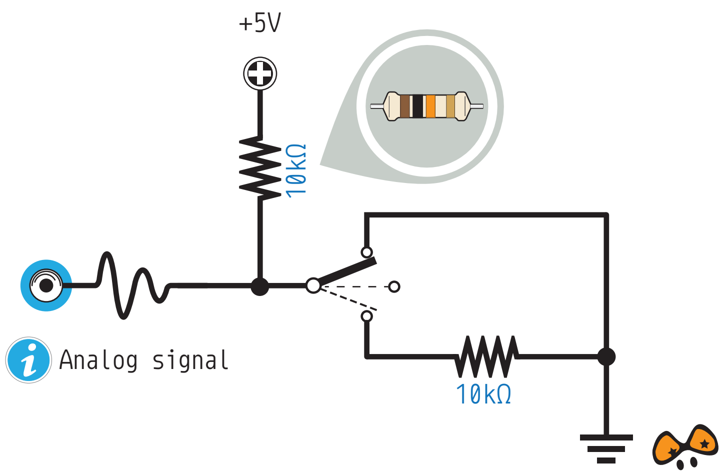
Toggle Switch

Basic Connections





Using One Analog Input



0-1.es/46

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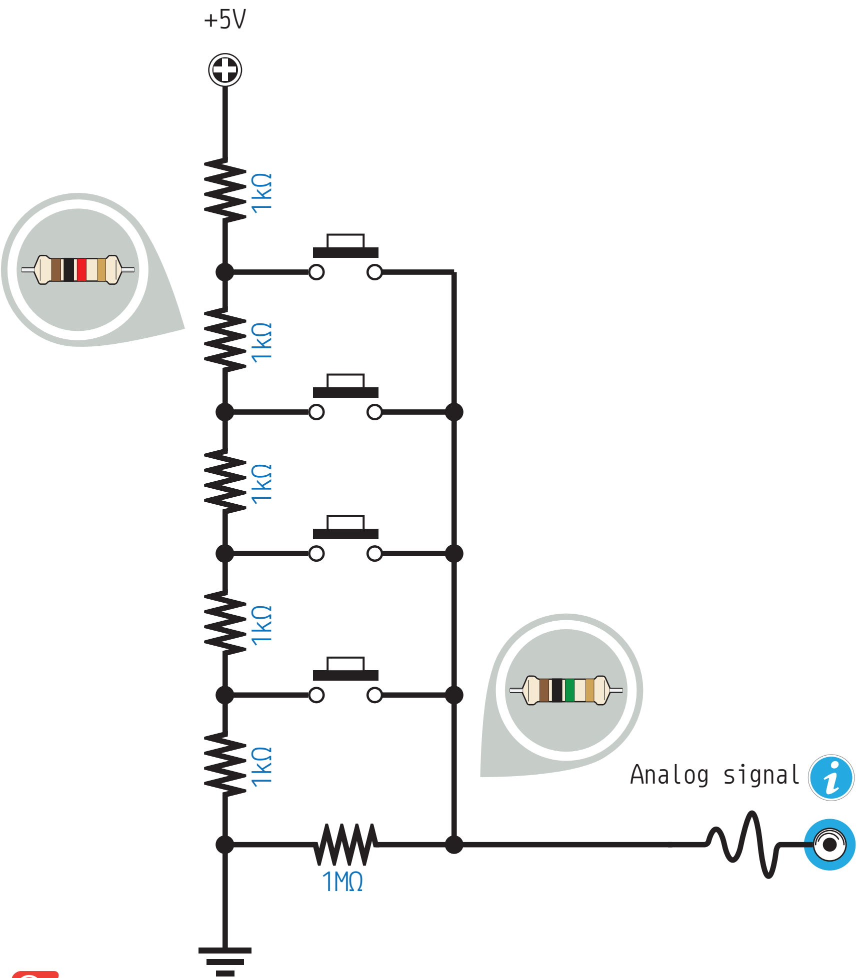
Multiple Pushbuttons

Basic Connections



This circuit cannot handle simultaneous button presses. In order to do that, you could use resistors with values at 2x increments with respect to the previous one (e.g., 1kΩ, 2kΩ, 4kΩ, 8kΩ). Hence by checking the voltage value, you should be able to tell which buttons are pressed simultaneously.

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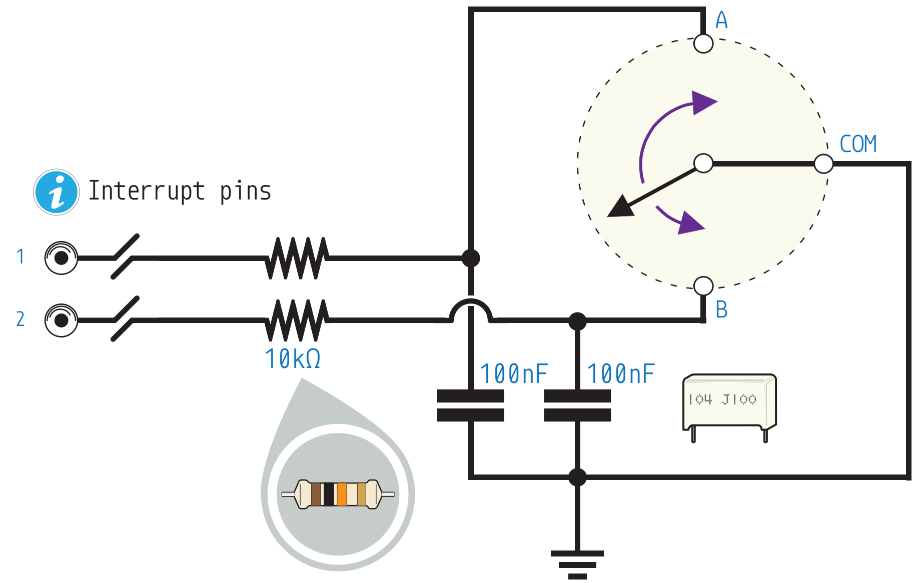
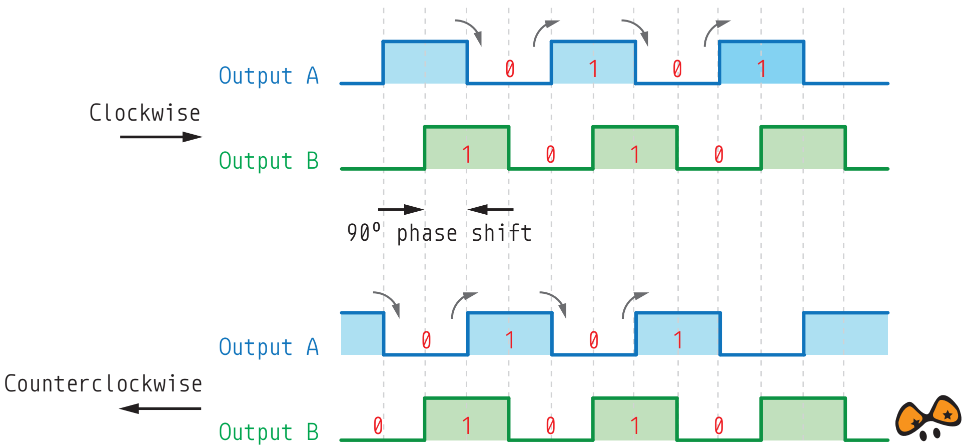
0-1.es/47

Rotary Encoder

Using Internal Pull-Up Resistors



How Rotary Encoders Work



0-1.es/48

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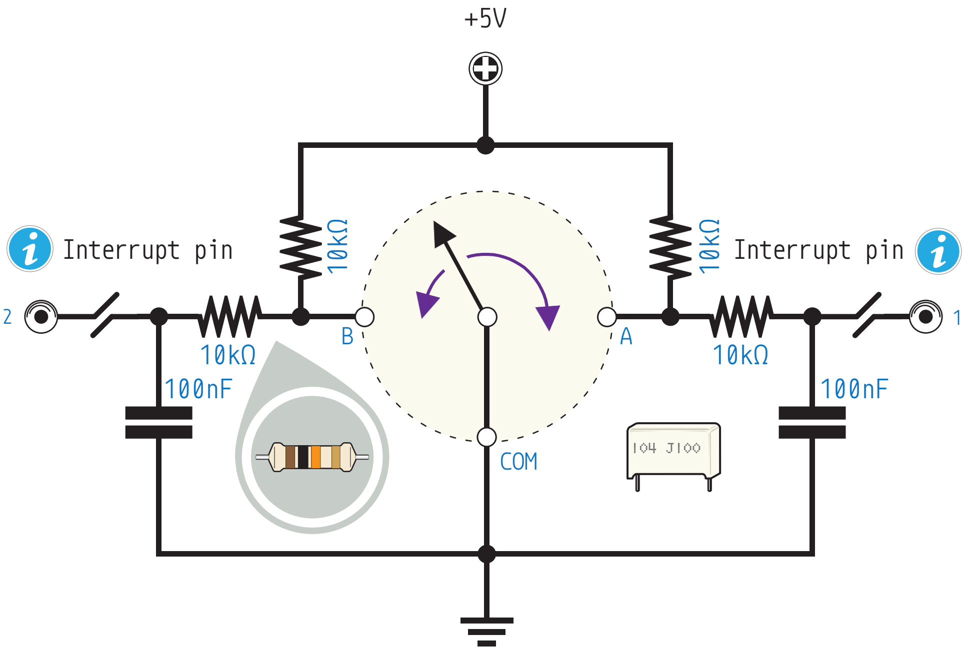
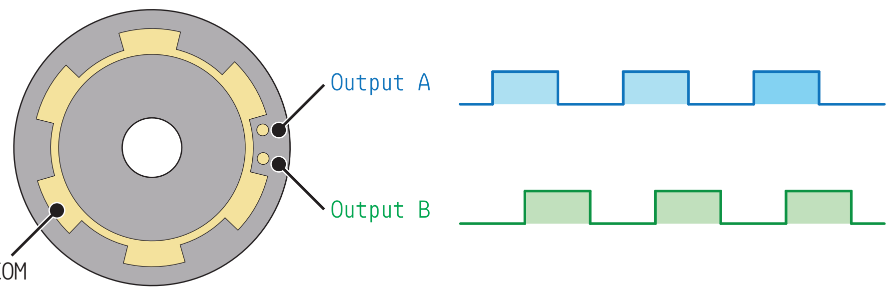
Rotary Encoder

Basic Connections



Inside a Rotary Encoder



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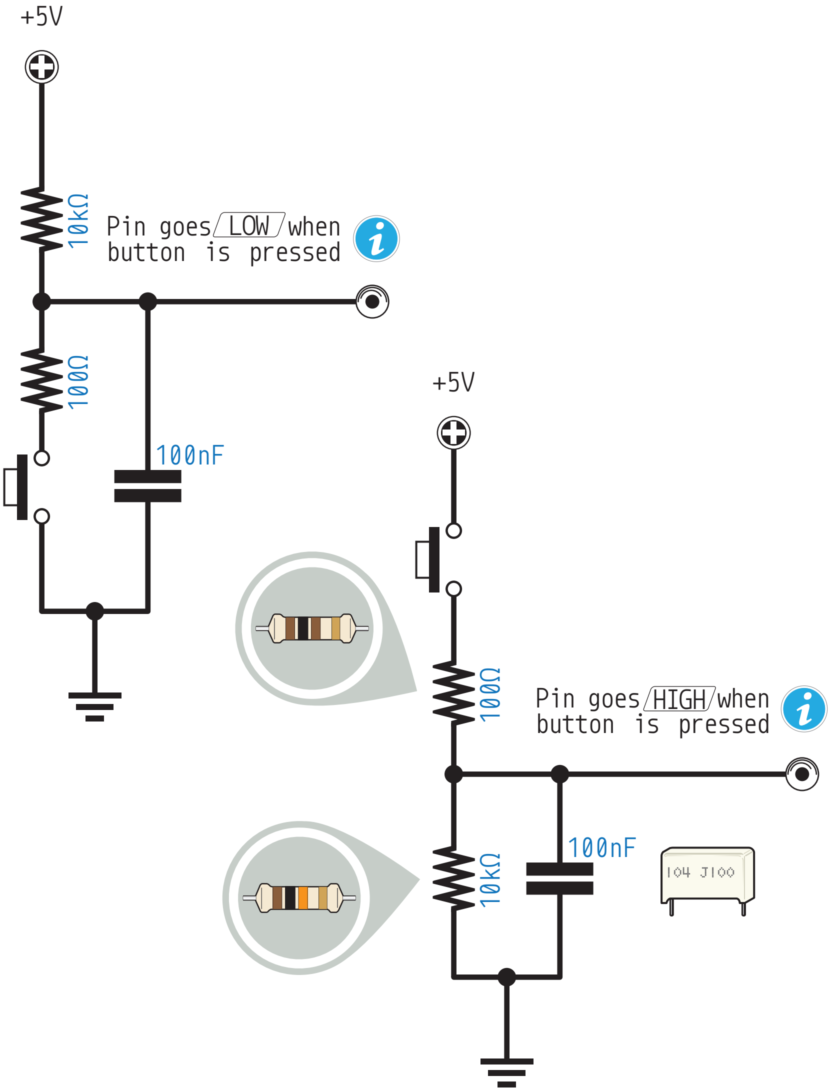
Simple Debouncing Circuit

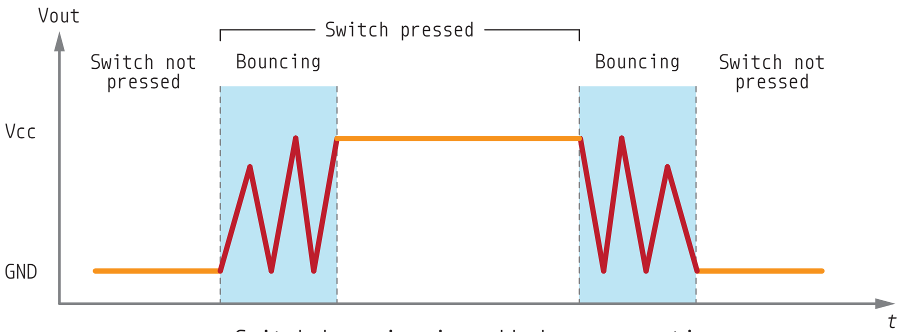
Basic Connections



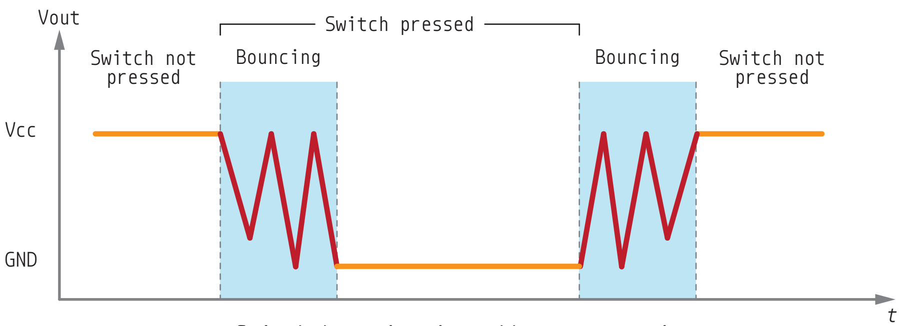
Debouncing

Theory

Contact bounce is a common problem associated with mechanical switches and relays. Switch and relay contacts are made up of spring metals which are forced to contact each other by an actuator. While they collide with each other there is a possibility of rebounding for some time before they make a stable contact. As a result of this effect there will be ON/OFF transitions generated as the contacts rapidly open and close. Contact bounce is an undesired behavior which generates multiple transitions for a single user input.



Switch bouncing in pull-down connection



Switch bouncing in pull-up connection

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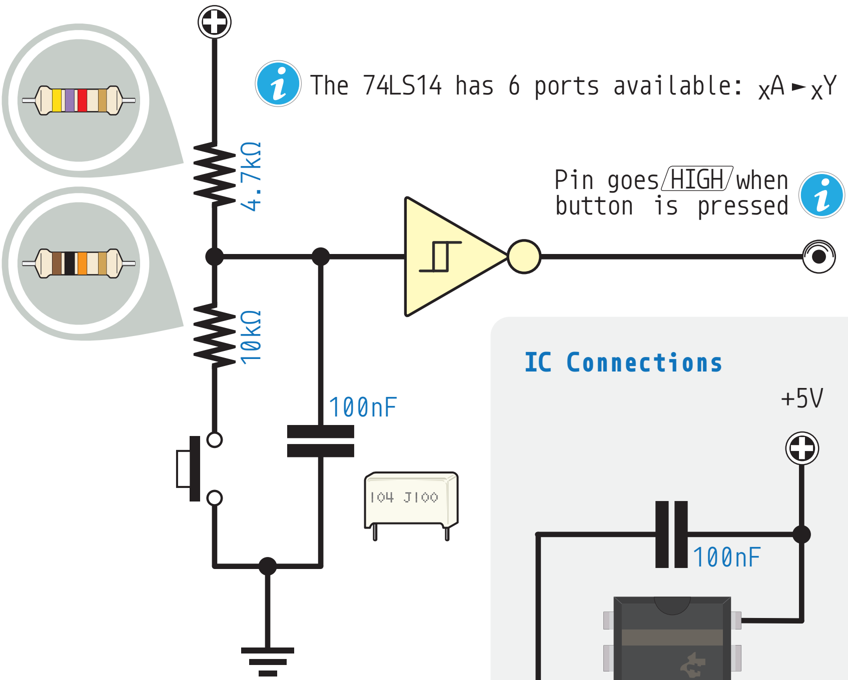
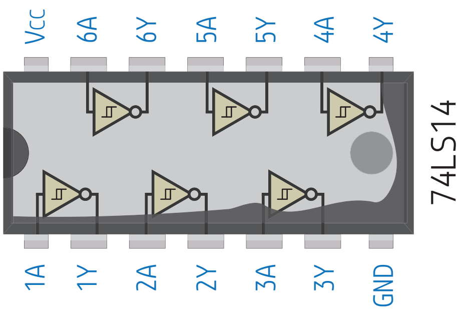
Debouncing

Using the 74LS14 Schmitt Trigger Inverter

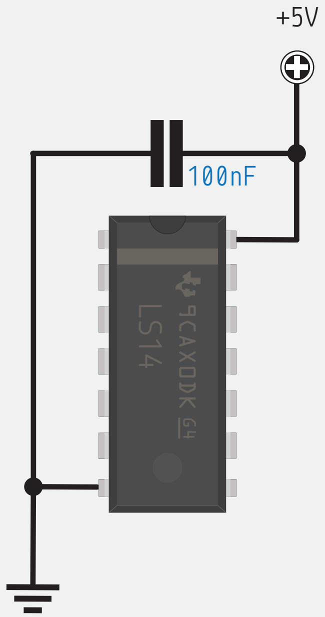


The 74LS14 has 6 ports available: xA ► xY

Pin goes HIGH when button is pressed



IC Connections



0-1.es/52

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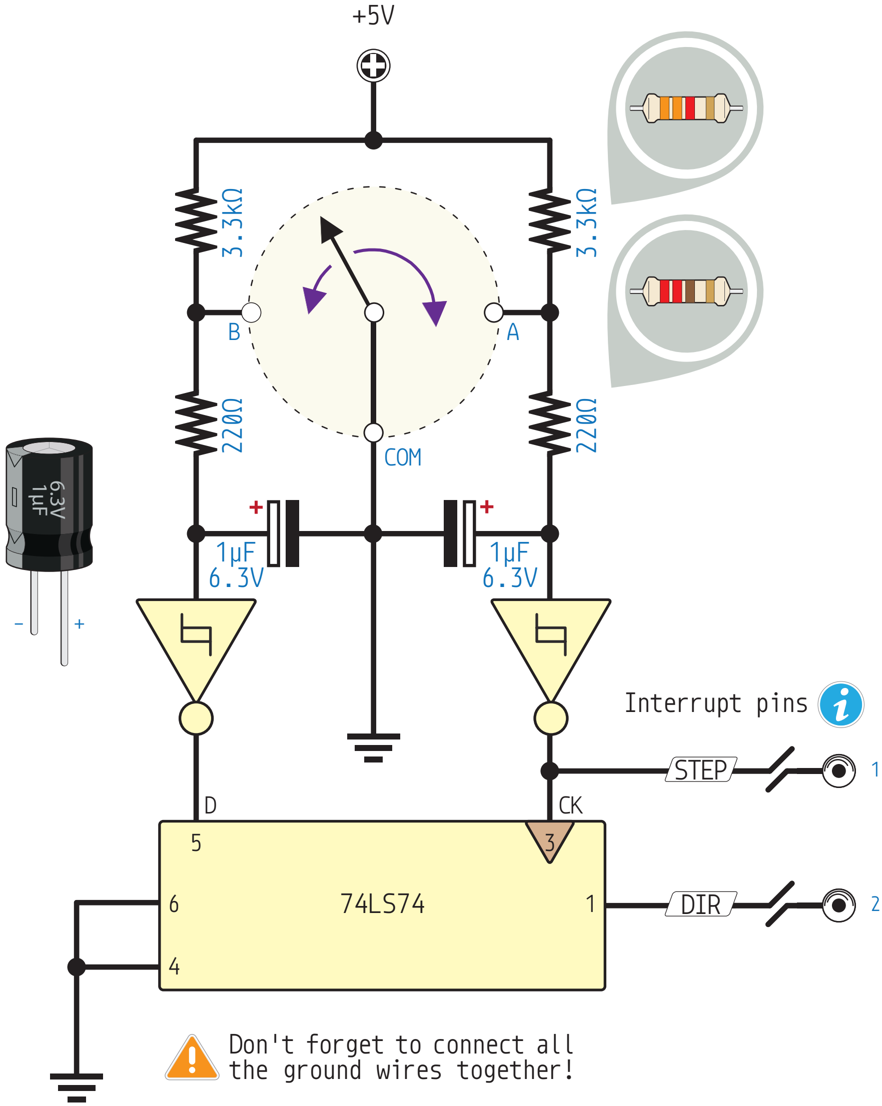
Rotary Encoder Debouncing

Using the 74LS14 & the 74LS74



Don't forget to connect all the ground wires together!

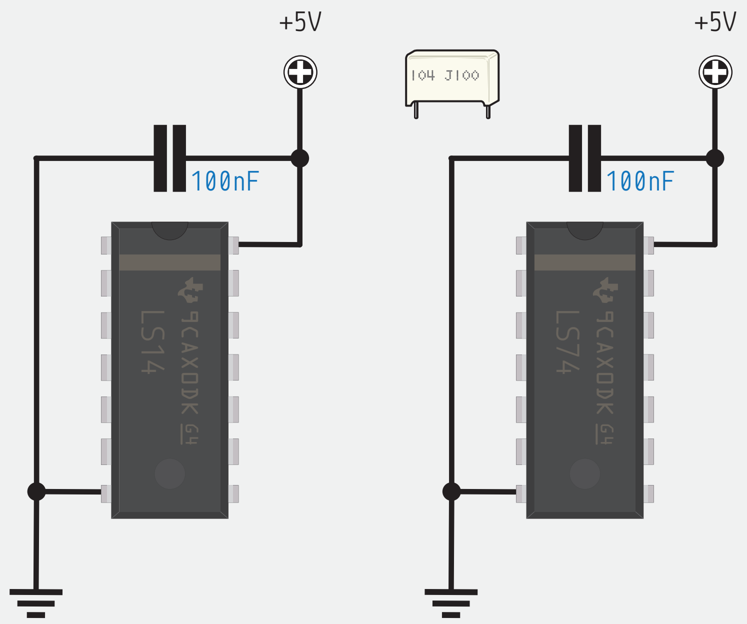
52

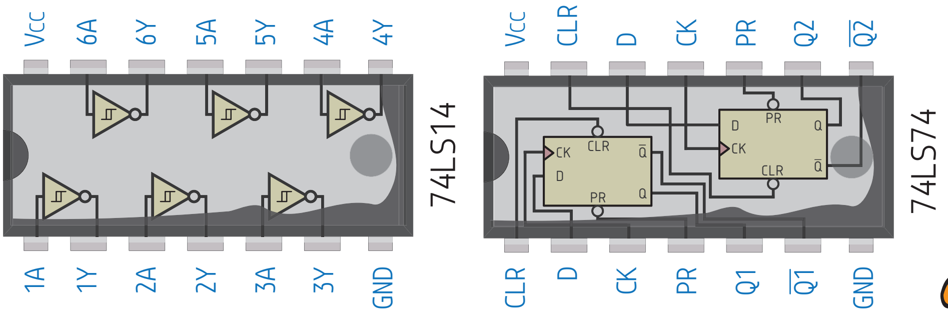
0-1.es/52

74LS14 & 74LS74

Pinout

74LS14 & 74LS74 Connections





0-1.es/53

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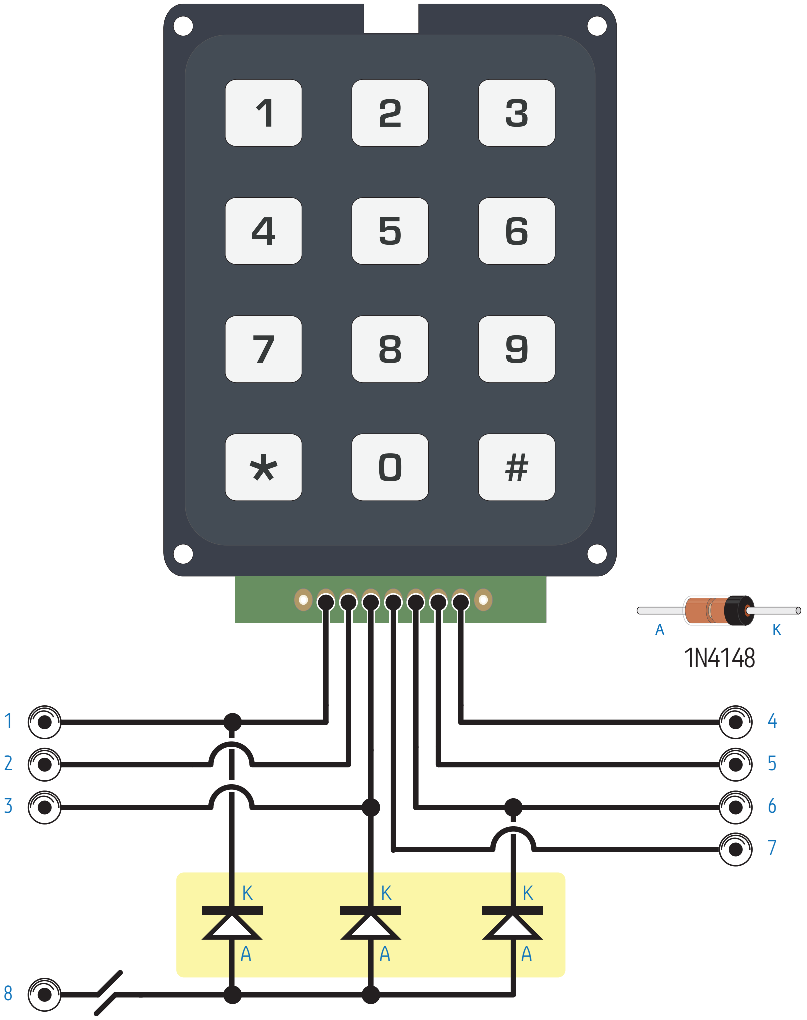
Keypad

Basic Connections



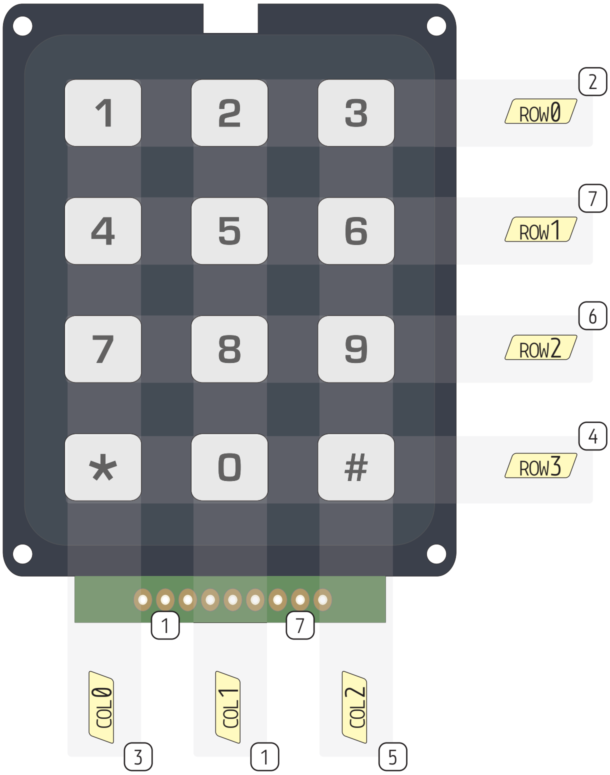
Interrupt pin

Optional interrupt circuit

53

0-1.es/53

Keypad
Pinout



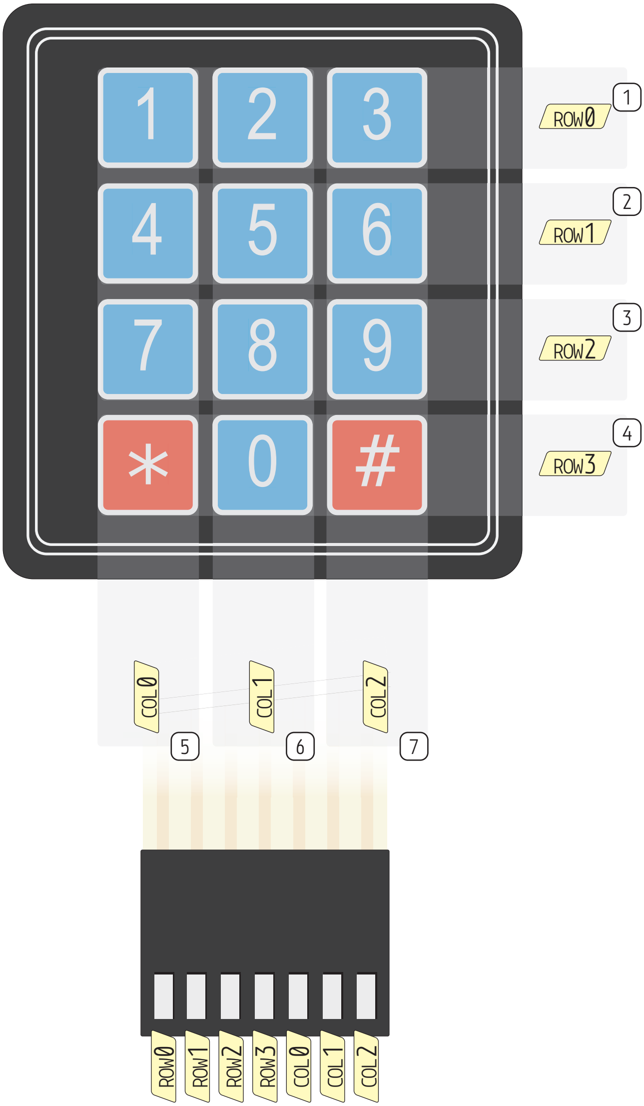
Keypads are ubiquitous in many electronic appliances and are used as input devices. Note that computer and calculator keypads have a different key arrangement compared to telephones, locks or ATMs.

0-1.es/54

54

Membrane Keypad

Pinout

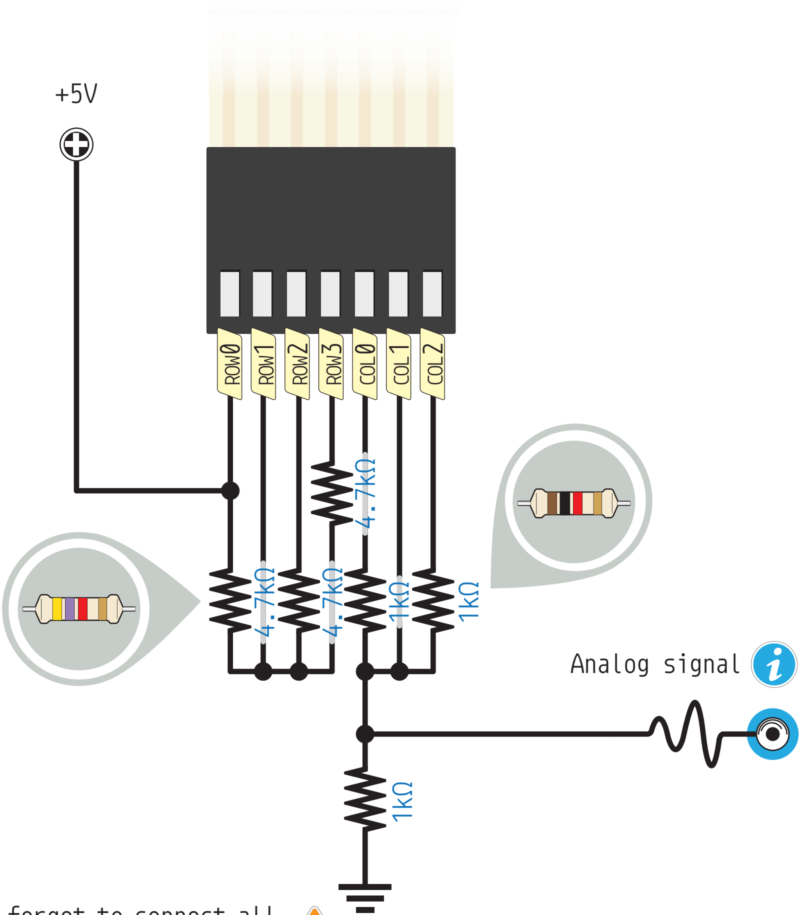


54

0-1.es/54

Keypad With 1 Analog Pin

Basic Connections



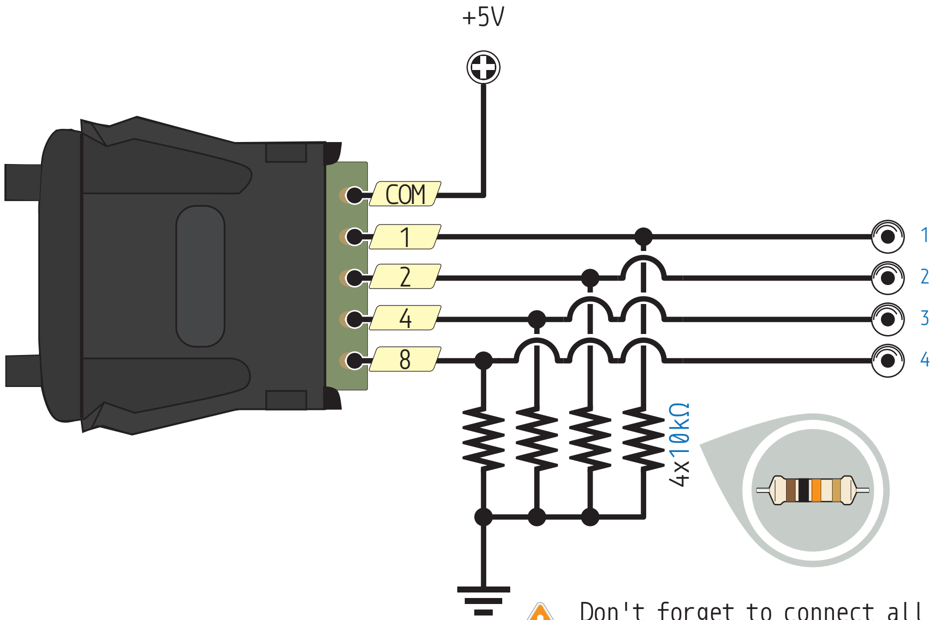
Don't forget to connect all
the ground wires together!

0-1.es/55

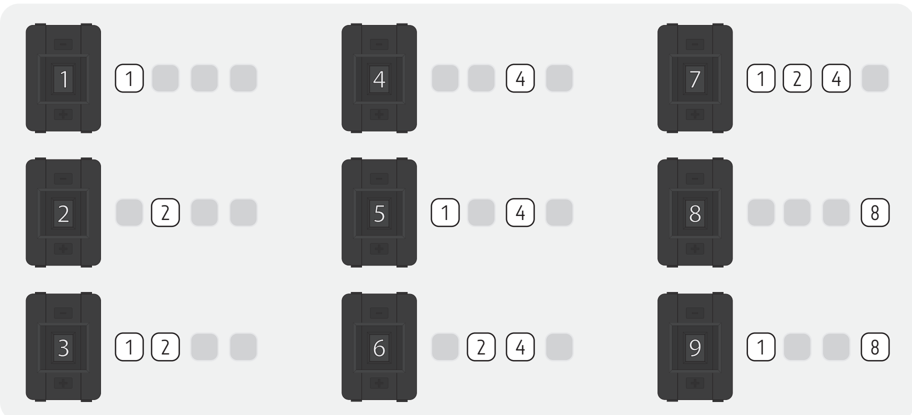
55

Thumbwheel Switch

Basic Connections



Don't forget to connect all the ground wires together!

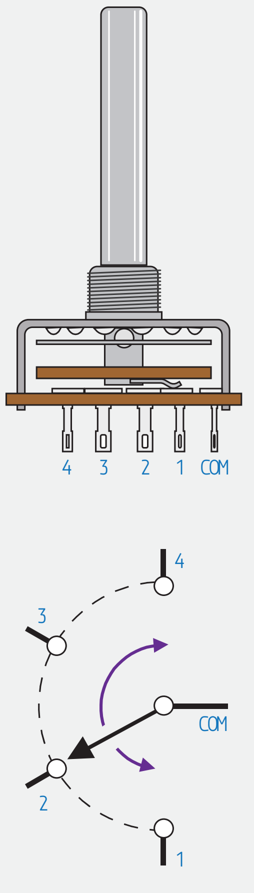


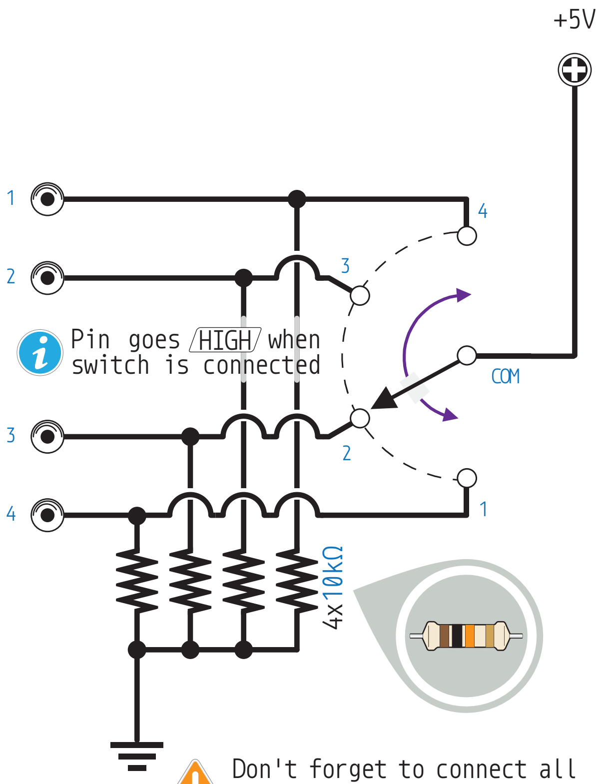
56

0-1.es/56

Rotary Switch

Basic Connections





Don't forget to connect all the ground wires together!

Rotary switches are switches that have fixed angular positions that click in place when the connection is established by rotating the shaft. You could build this circuit using just one analog pin as in the **Multiple Pushbuttons** sheet by replacing the pushbuttons in that circuit with a rotary switch.

0-1.es/57

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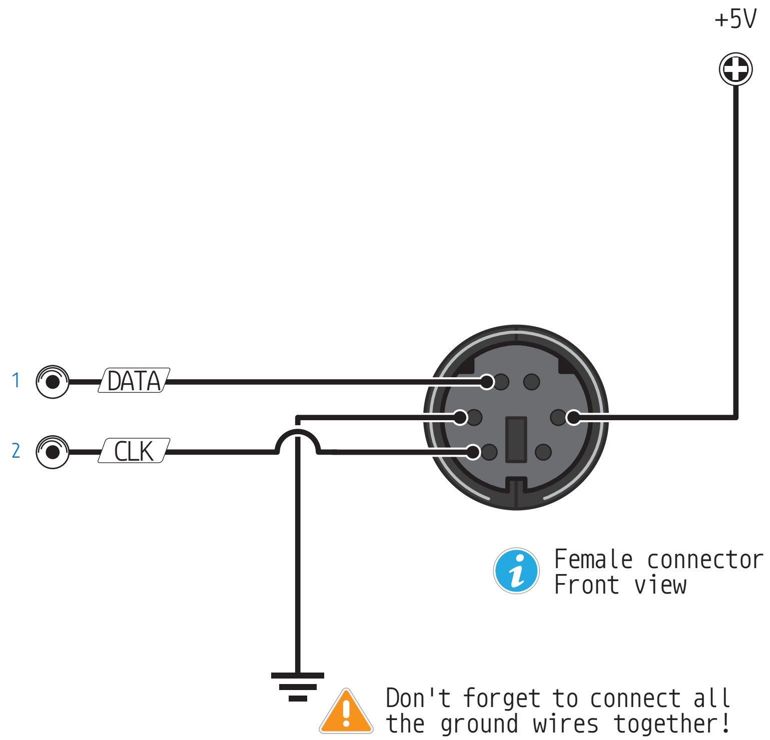
PS/2 Keyboard

Basic Connections

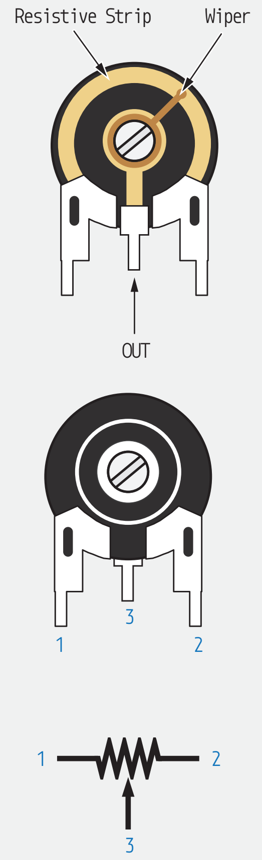


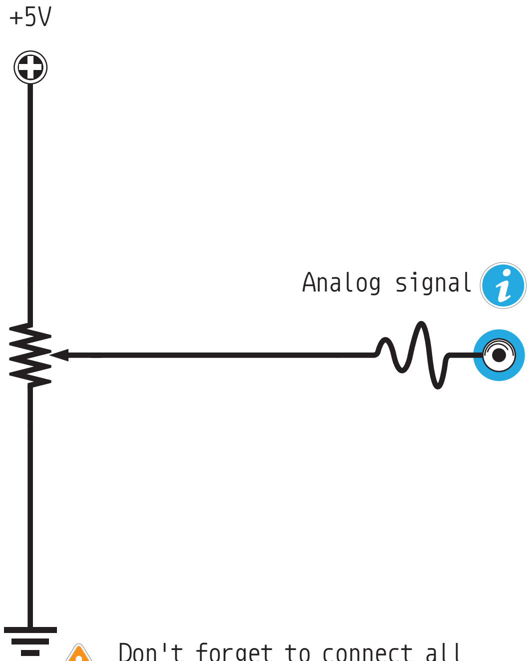
PS/2 is a simple synchronous serial protocol that uses only two wires for communication. Due to its simplicity, PS/2 keyboards are widely used with simple microcontroller boards. PS/2 keyboards can send the equivalent ASCII value of the key that has been pressed.

58

0-1.es/58

Trimmer
Basic Connections



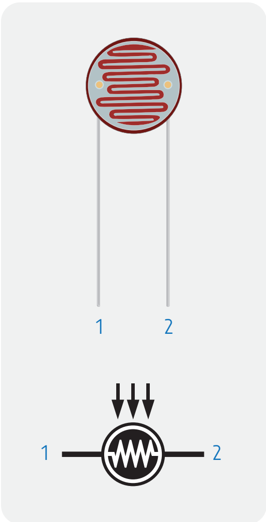


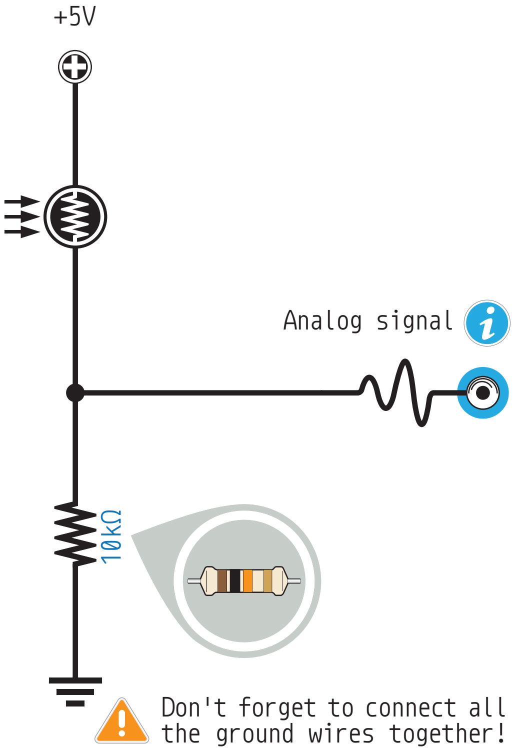
Don't forget to connect all
the ground wires together!

Trimmers are manually-adjustable, variable resistors with three terminals. Two terminals are connected to a resistive element and the third terminal is connected to an adjustable wiper. In this circuit, the position of the wiper determines the output voltage.

Photoresistor (LDR)

Basic Connections





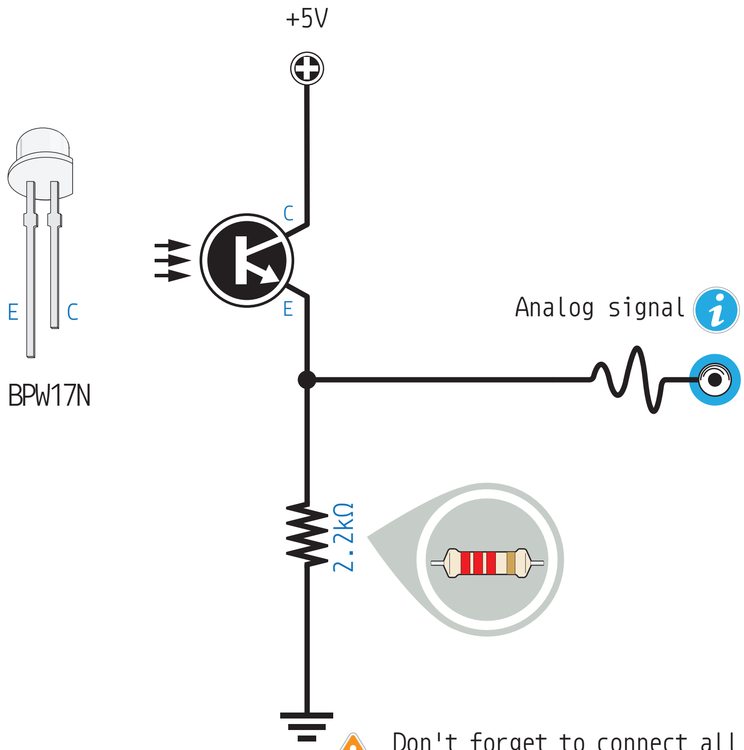
Photoresistors or photocells are light-controlled variable resistors. The resistance of a photoresistor decreases with increasing incident light intensity. Photoresistors can be applied in light-sensitive detector circuits and light-activated switching circuits.

60

0-1.es/60

Phototransistor

Basic Connections



Don't forget to connect all the ground wires together!

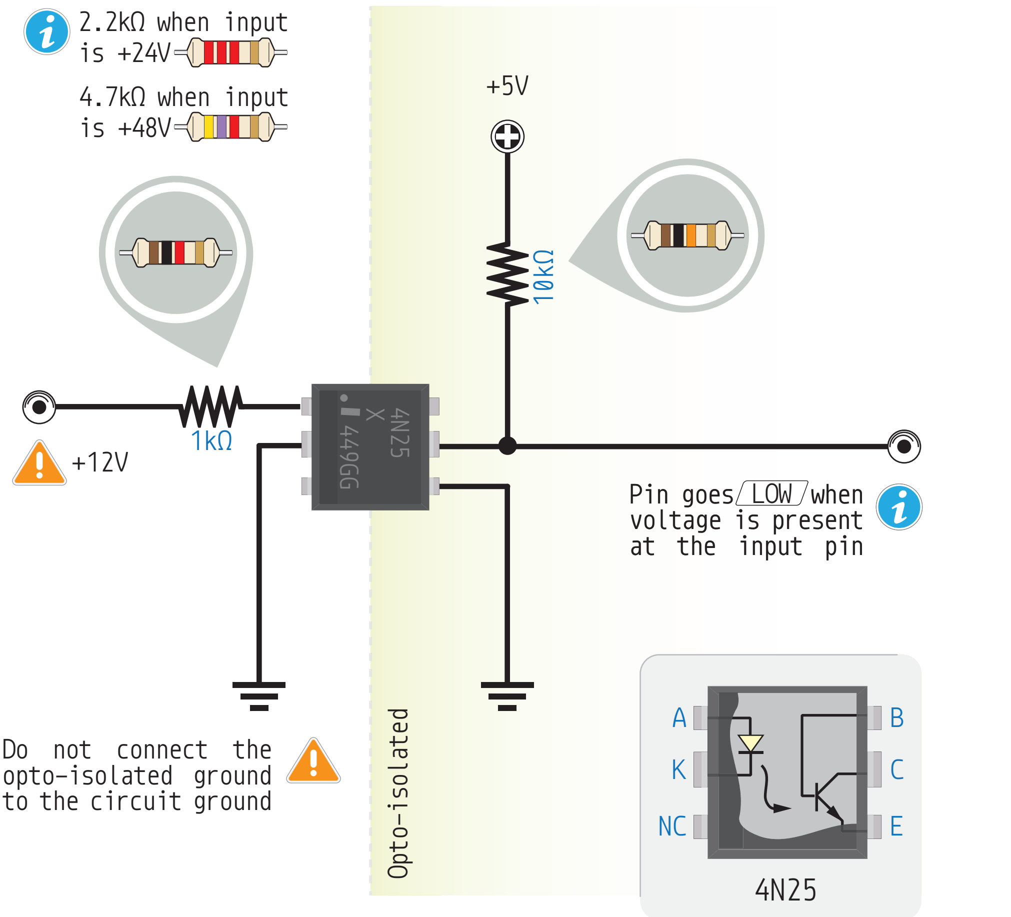
Phototransistors are light-sensitive transistors. Light reaches the the base-collector junction, where electrons are generated, and the current is amplified by the current gain. Phototransistors are faster than photoresistors and slower than photodiodes, but they are less sensitive to temperature.

0-1.es/61

61

Opto-Isolated DC Input

Using the 4N25 Optocoupler

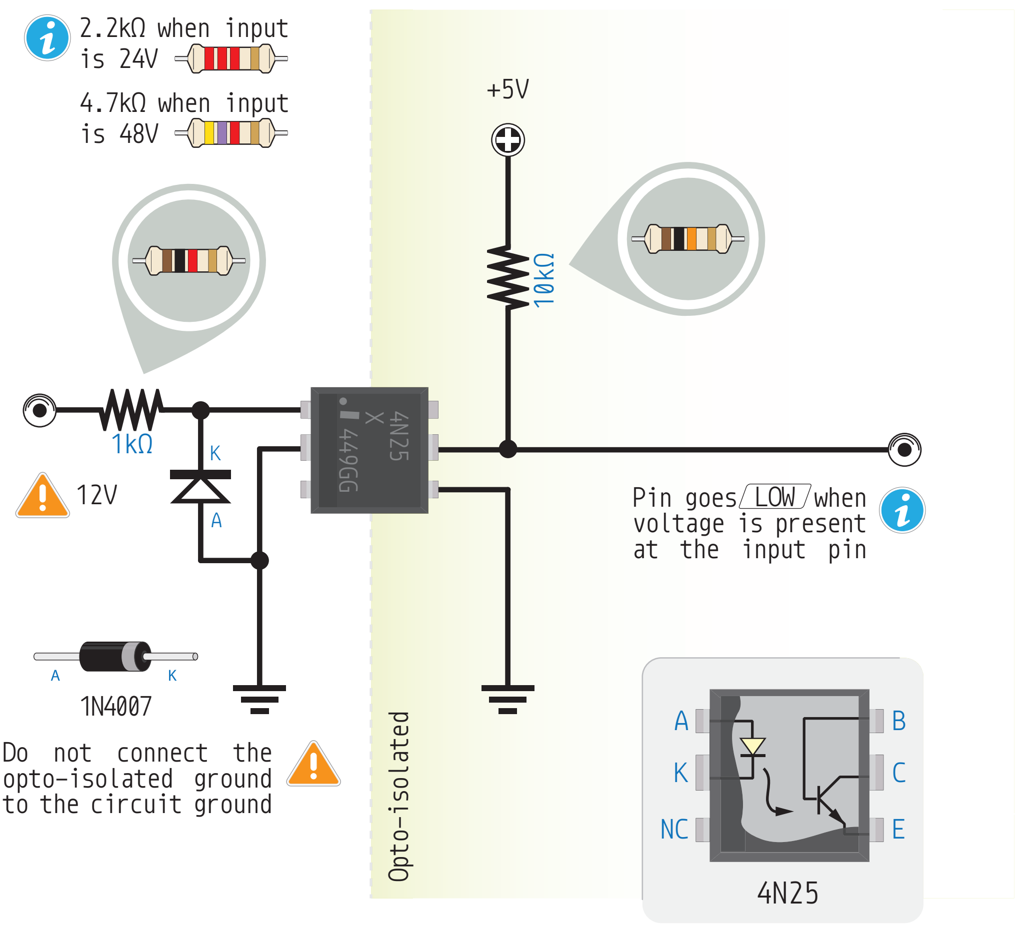


62

0-1.es/62

Opto-Isolated AC Input

Using the 4N25 Optocoupler

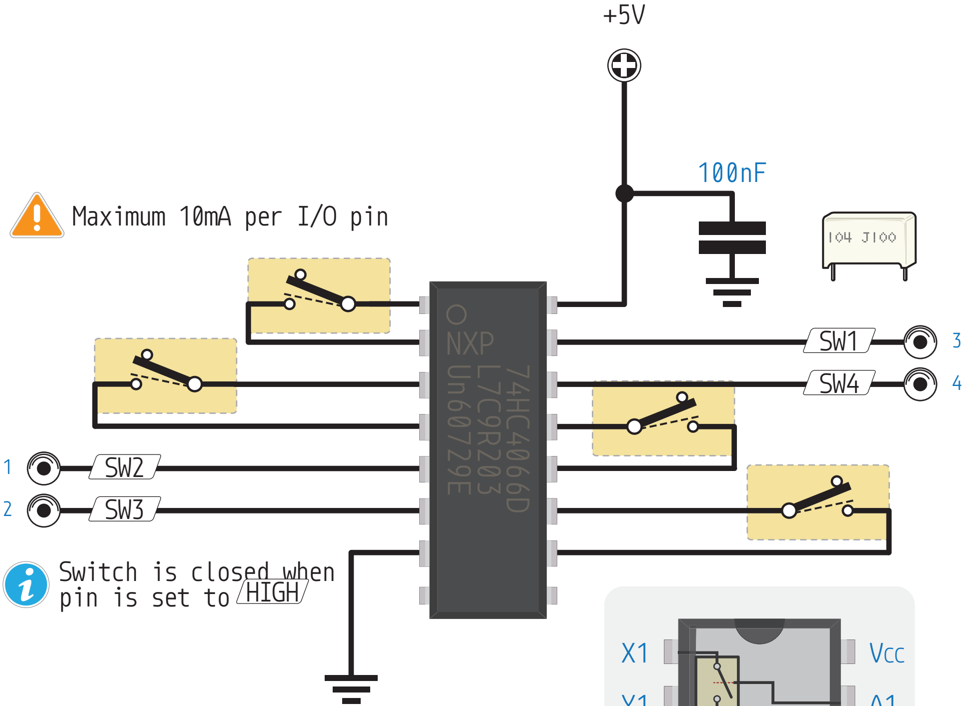


0-1.es/63

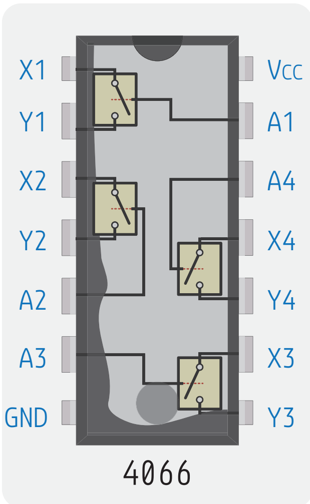
63

SPST CMOS Analog Switch

Using the 4066 Quad Bilateral Switch



Don't forget to connect all the ground wires together!



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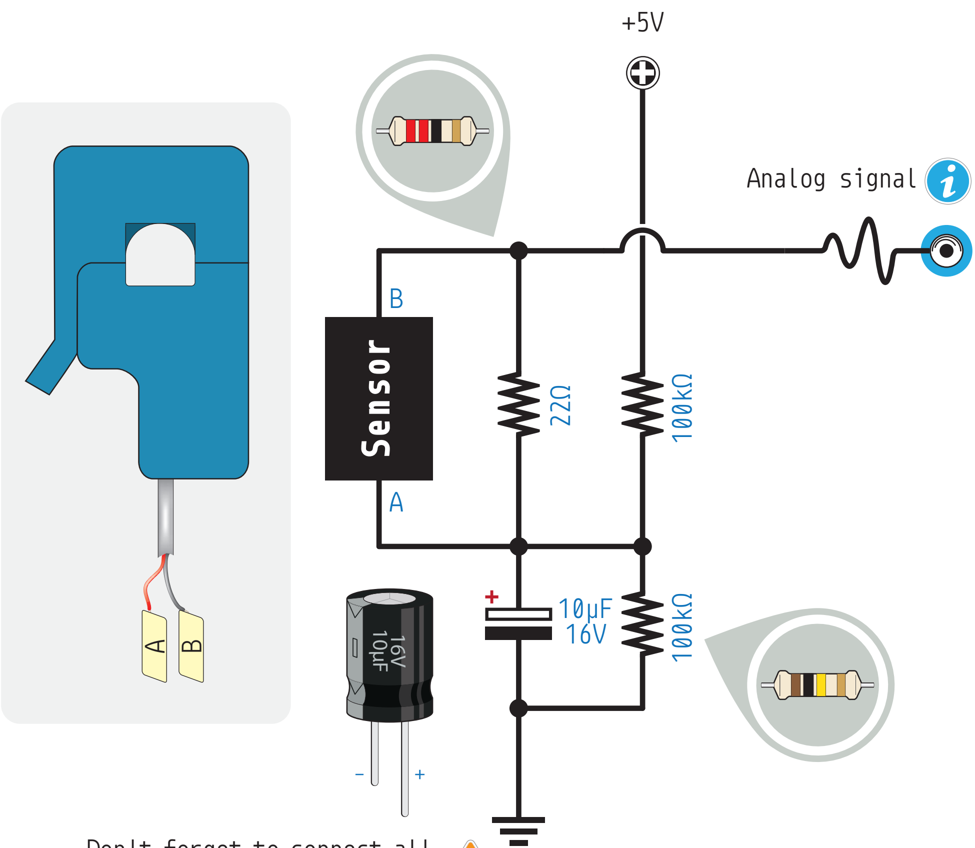
0-1.es/64

AC Current Sensor

Basic Connections

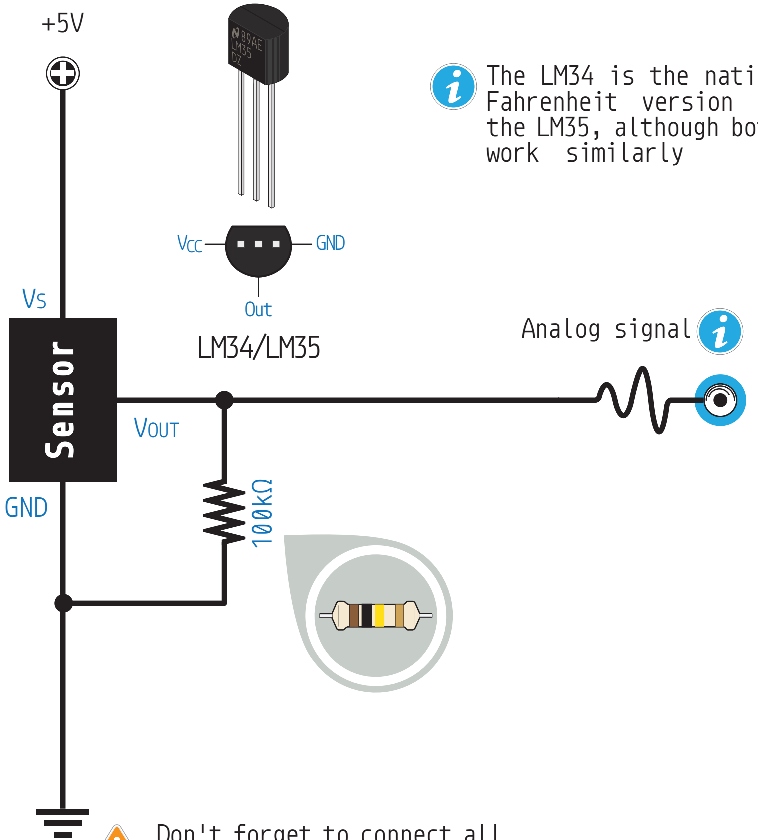


Don't forget to connect all the ground wires together!

These non-invasive current sensing probes are an affordable solution for measuring high AC current. They are also called CT (current transformer) sensors because they act like current transformers, delivering a fraction of the current measured through magnetic induction.

LM34/LM35 Temperature Sensor

Basic Connections



The LM34 is the native Fahrenheit version of the LM35, although both work similarly

Don't forget to connect all the ground wires together!

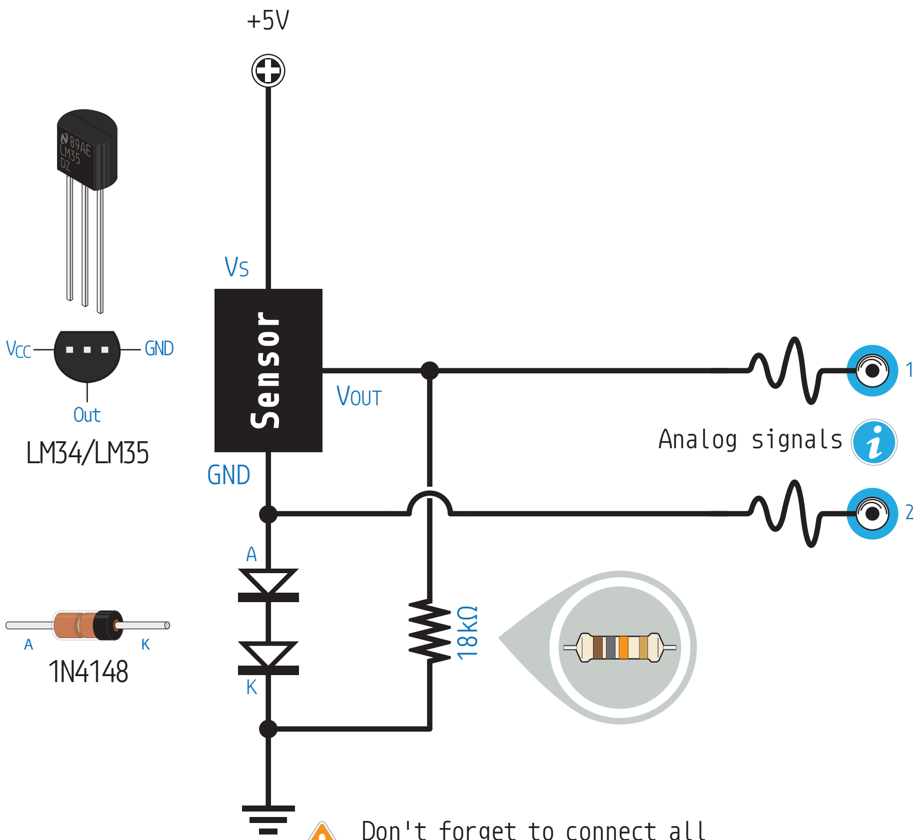
The LM35 is an analog, precision temperature sensor. This circuit allows for a measuring range of 2°C to +150°C (35.6°F to +302°F) with a temperature accuracy of ±0.5°C (0.9°F). The output of the sensor is linear with respect to the measured temperature, increasing its output voltage by 10mV per degree Celsius.

66

0-1.es/66

LM34/LM35 Temperature Sensor

Full Range



Don't forget to connect all the ground wires together!

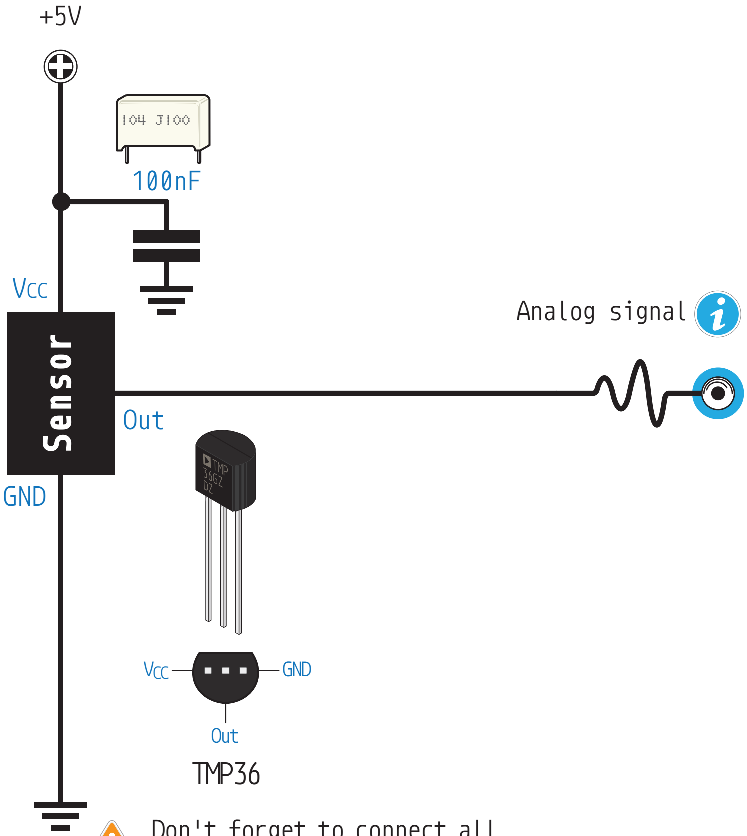
This circuit allows the LM35 to achieve its full potential, allowing for a temperature measuring range of -55°C to +150°C (-67°F to +302°F). The voltage is measured between both analog signal outputs, so you need to read the values with your microcontroller and obtain the absolute value of the difference.

0-1.es/67

67

TMP36 Temperature Sensor

Basic Connections



Don't forget to connect all the ground wires together!

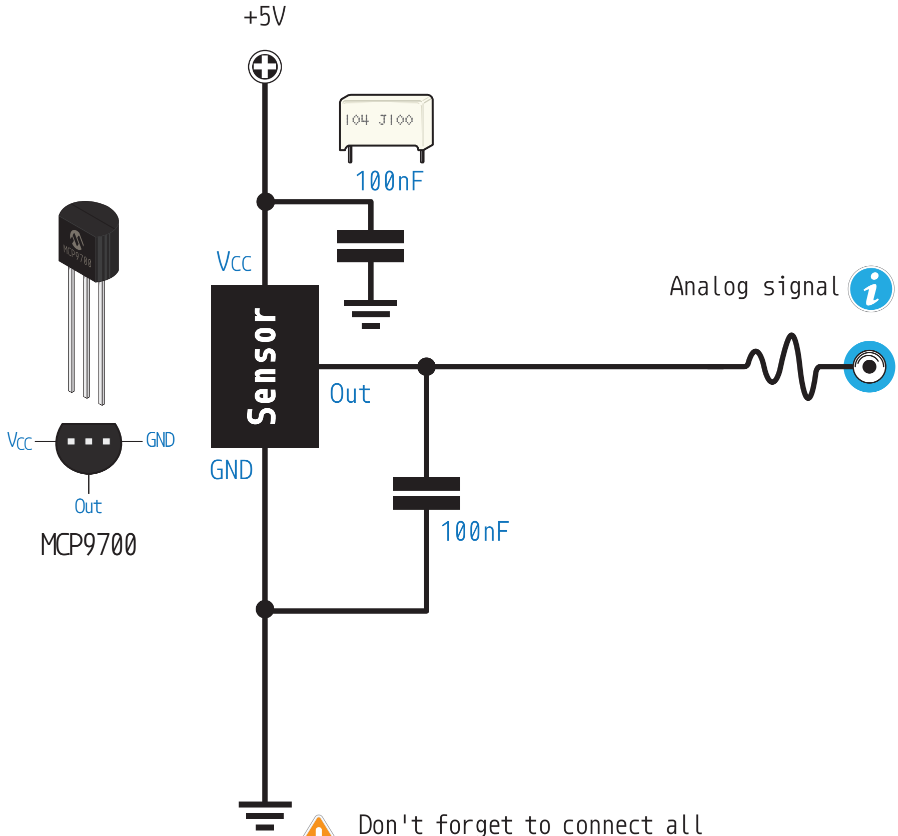
The TMP36 is an analog temperature sensor with a measuring range of -40°C to +125°C (-40°F to +257°F). It has a temperature accuracy of ±2°C and it is very linear.

68

0-1.es/68

MCP9700 Temperature Sensor

Basic Connections



Don't forget to connect all the ground wires together!

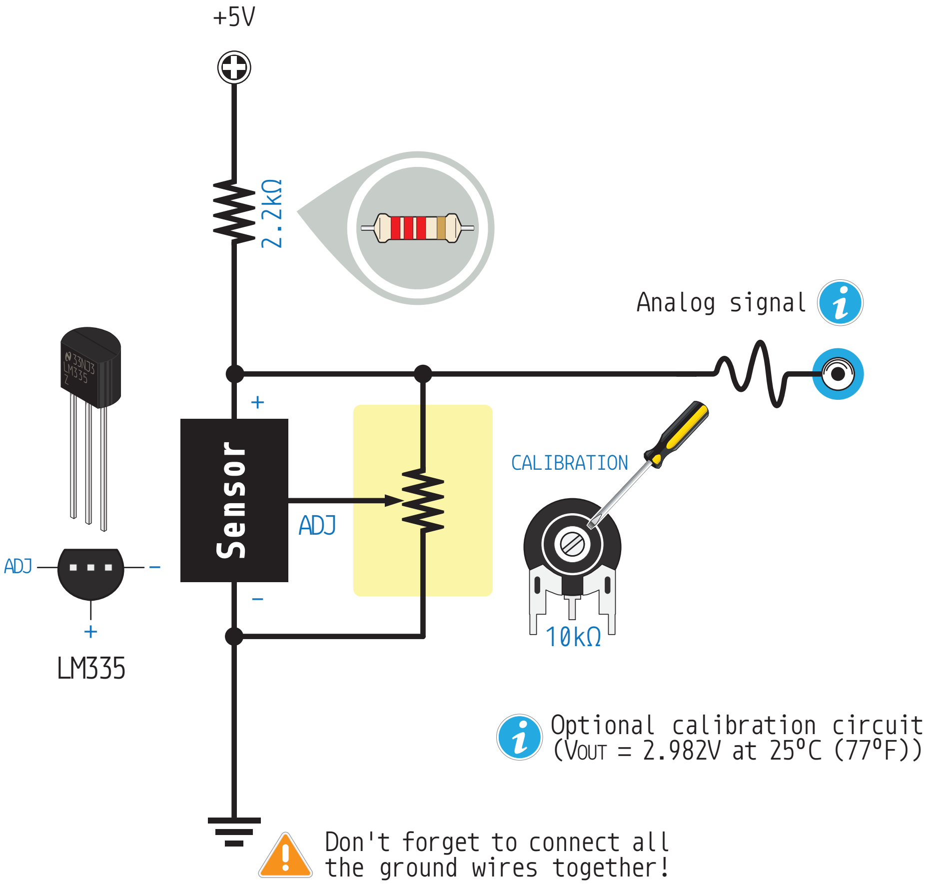
The MCP9700 is an analog temperature sensor with a measuring range of −40°C to +125°C (-40°F to +257°F). It has a temperature accuracy of ±2°C and it is very linear.

0-1.es/69

69

LM335 Temperature Sensor

Basic Connections



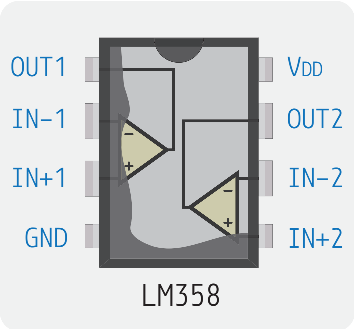
The LM335 is a digital, linear, precision temperature sensor. It has a temperature measuring range of -55°C to +150°C (-67°F to +302°F) with an accuracy of 1°C (1.8°F). The LM335 measures temperature in Kelvin, so you will need to subtract 273 from your measurement to obtain the temperature in Celsius.

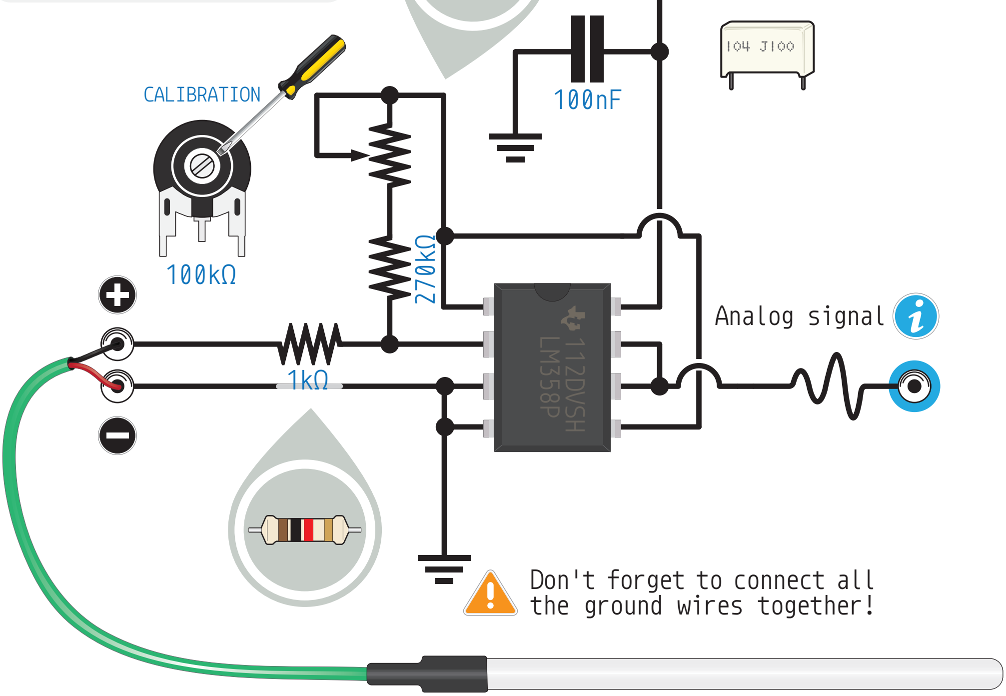
70

0-1.es/70

Thermocouple

Using the LM358 Op-Amp





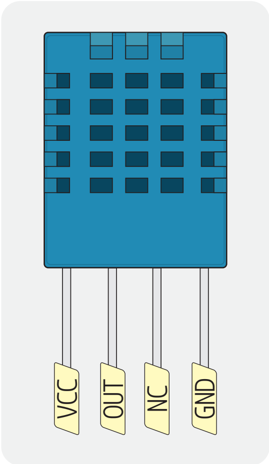
Check wiring color codes online

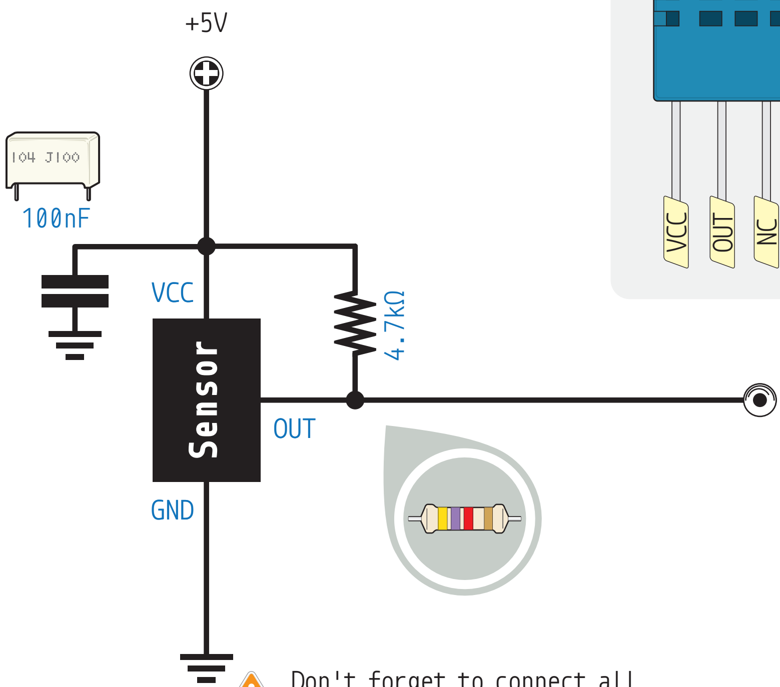
0-1.es/71

71

DHT11 Temp. & Humidity Sensor

Basic Connections





Don't forget to connect all the ground wires together!

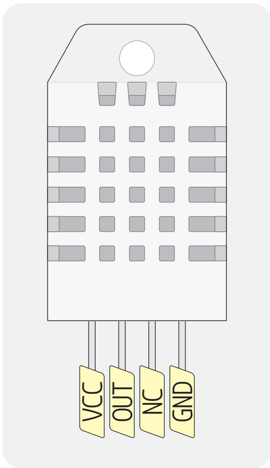
The DHT11 is a digital, low cost, medium precision humidity and temperature sensor. Its measuring ranges are 20 to 90% (±5%) for relative humidity and 0°C to 50°C (±2°C) (32°F to 122°F (±3.6°F)) for temperature.

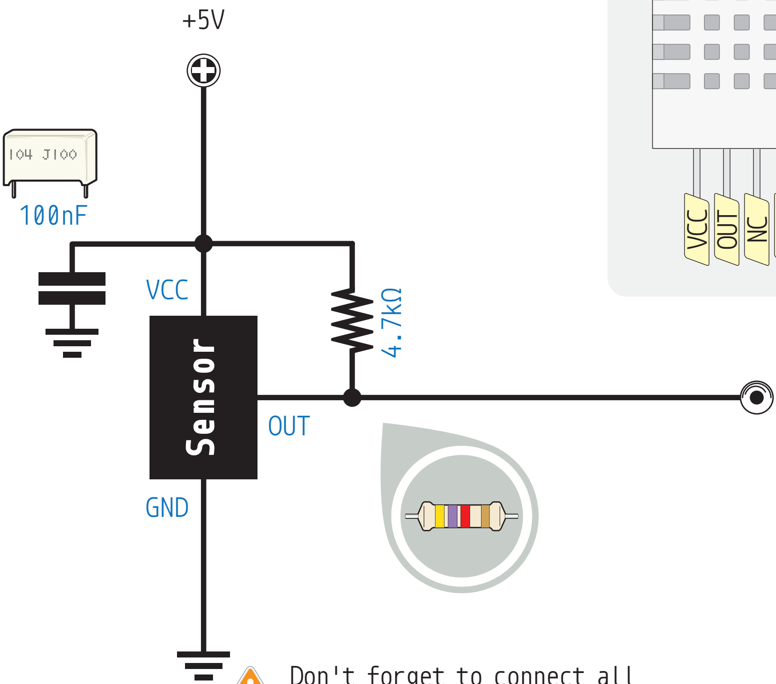
72

0-1.es/72

DHT22 Temp. & Humidity Sensor

Basic Connections





Don't forget to connect all the ground wires together!

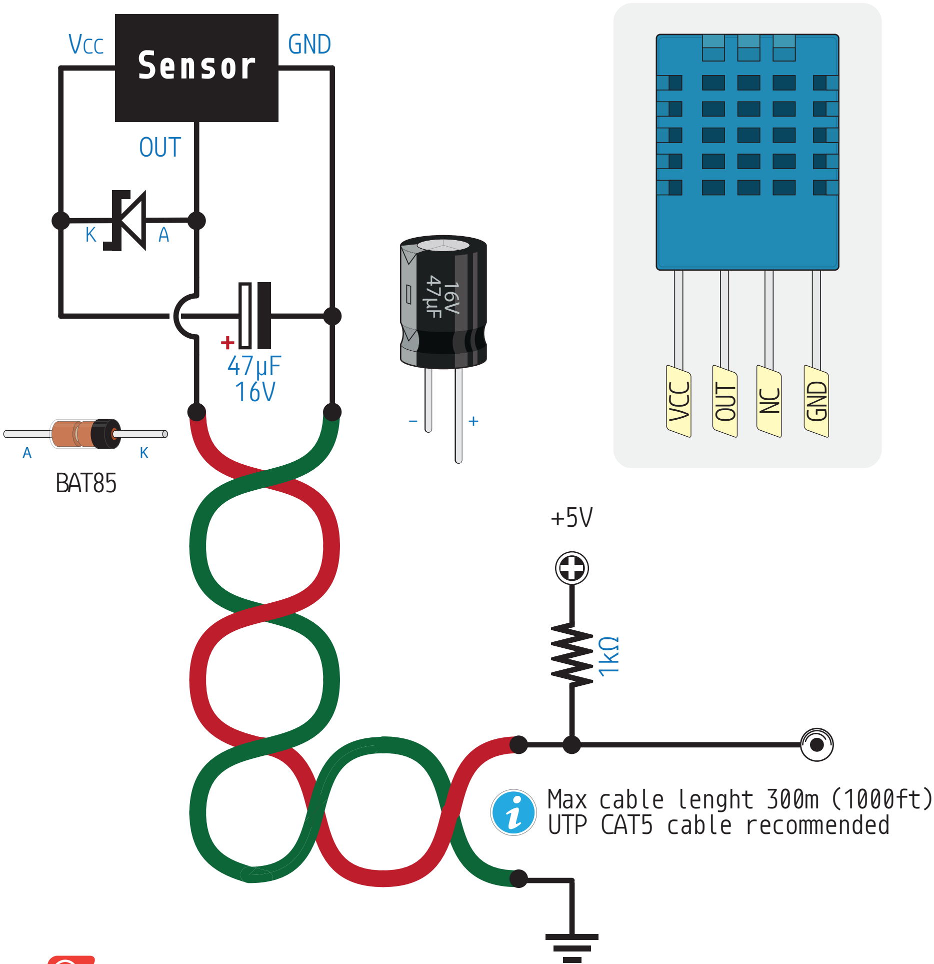
The DHT22 (also called AM2302) is a digital temperature and humidity sensor very similar to the DHT11, except it offers higher-precision readings. Its measuring ranges are 0 to 90% (±2%) for relative humidity and -40°C to 80°C (±0.5°C) (-40°F to 176°F (±0.9°F)) for temperature.

0-1.es/73

73

DHT11/DHT22 2-Wire Connection

Basic Connections



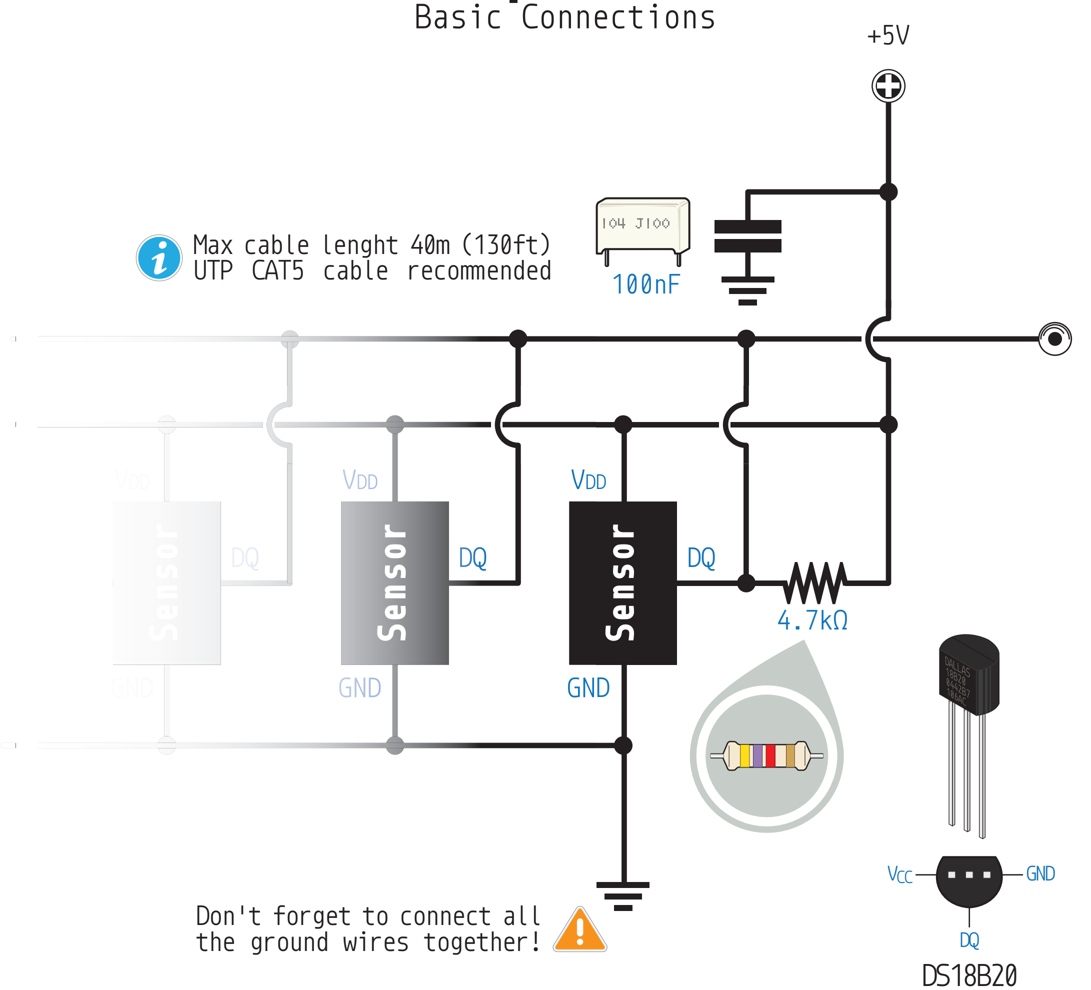
This 2-wire connection circuit allows for reliable measurements over long distances. Twisted pair cables like UTP CAT5, used in computer networks such as Ethernet, are affordable and ubiquitous.

74

0-1.es/74

DS18B20 Temperature Sensor

Basic Connections



Max cable lenght 40m (130ft)
UTP CAT5 cable recommended

Don't forget to connect all
the ground wires together!

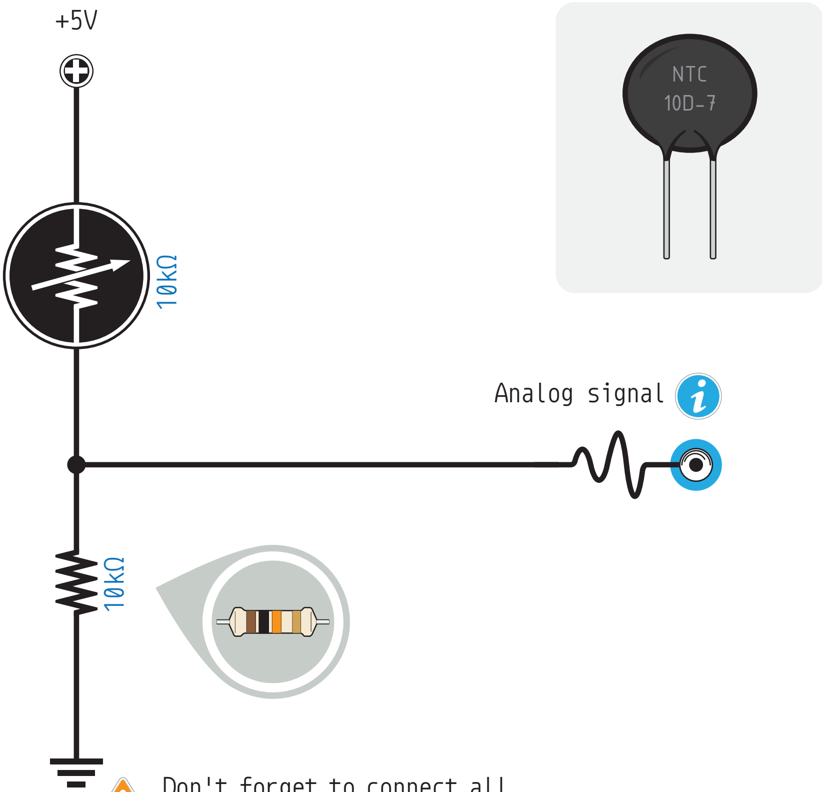
The DS18B20 is a digital, precision temperature sensor with a measuring range of -55°C to +150°C (±0.5°C) (-67°F to +257°F (±0.9°F)). Its 1-wire interface requires only one port pin for communication, providing the temperature value with just a few lines of code and allowing multiple sensors to run in parallel.

0-1.es/75

75

NTC Thermistor

Basic Connections



Don't forget to connect all
the ground wires together!

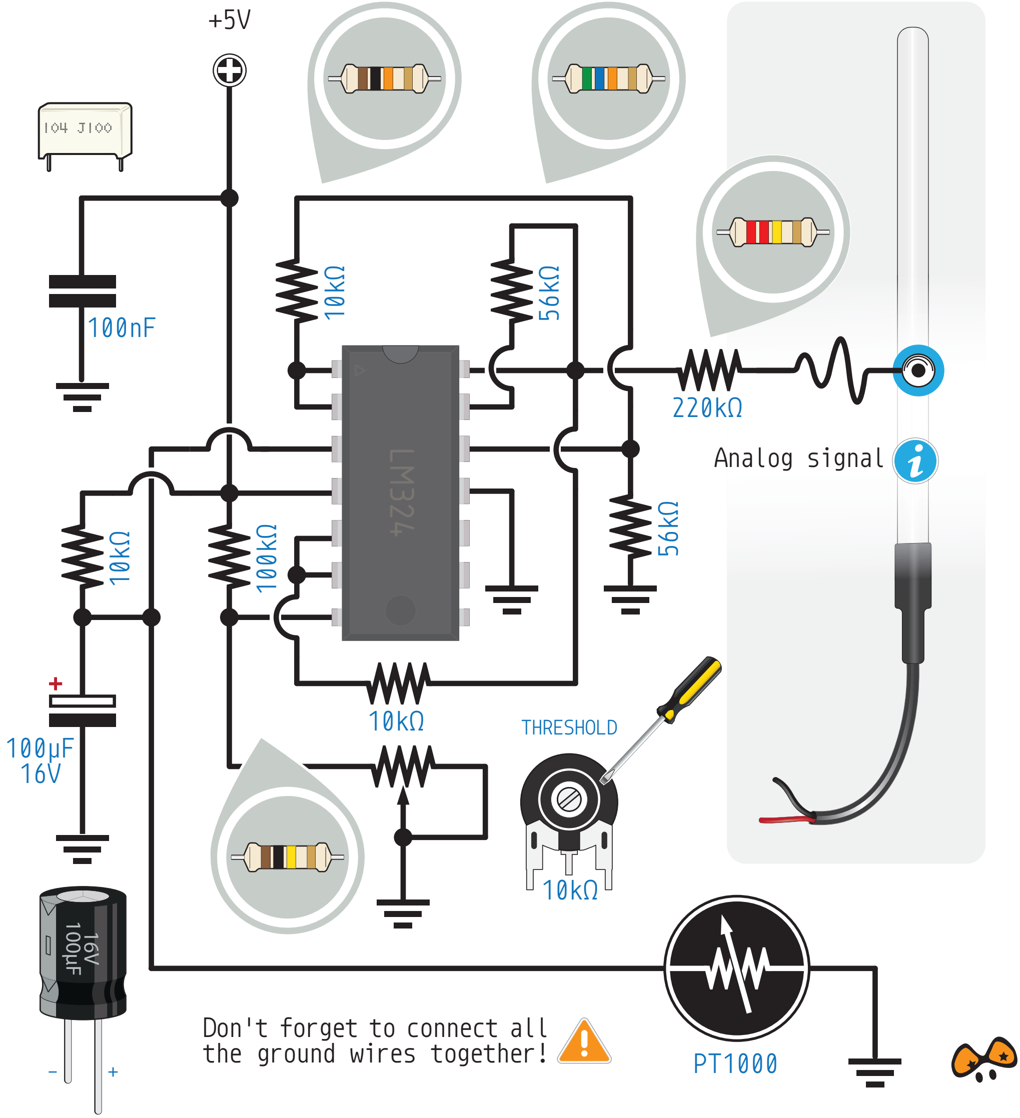
Thermistors (thermally-sensitive resistors) are a type of resistor whose resistance is dependent on temperature. Their temperature range is typically -55°C to 200°C (-67°F to 392°F). Thermistors are affordable, sensitive but not very linear.

76

0-1.es/76

RTD Temperature Sensor

Using a PT1000 Sensor



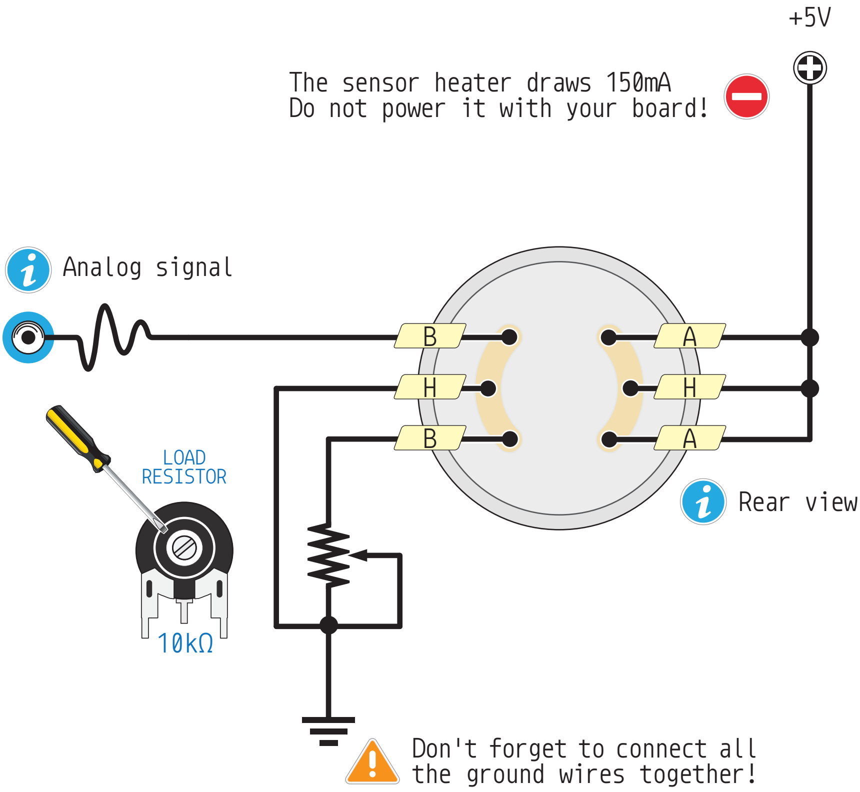
Don't forget to connect all the ground wires together!

0-1.es/77

77

Gas Sensor

Using an MQ Series Sensor



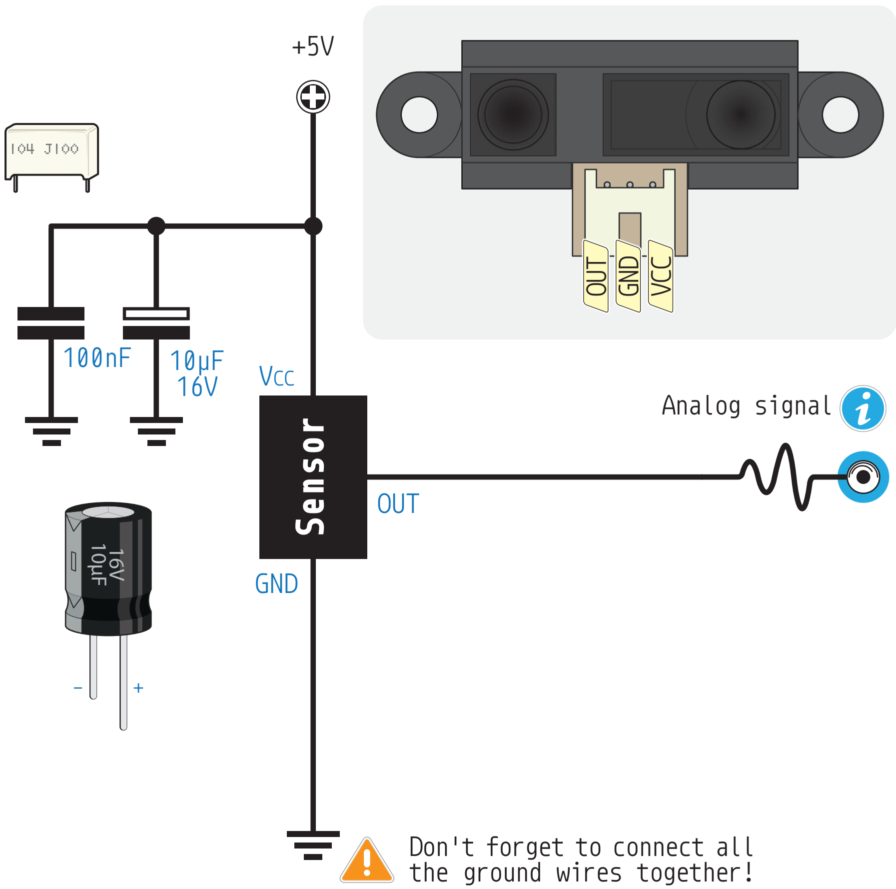
The MQ series of gas sensors use a small heater inside with an electro-chemical sensor. They are sensitive for a range of gasses at room temperature such as methane, butane, propane, natural gas, LPG, smoke, alcohol, ethanol, ozone, hydrogen, benzene, hydrogen sulfide, toluene, acetone, CO2, CO, etc.

78

0-1.es/78

Sharp GP2Y0A21 Distance Sensor

Basic Connections



Don't forget to connect all the ground wires together!

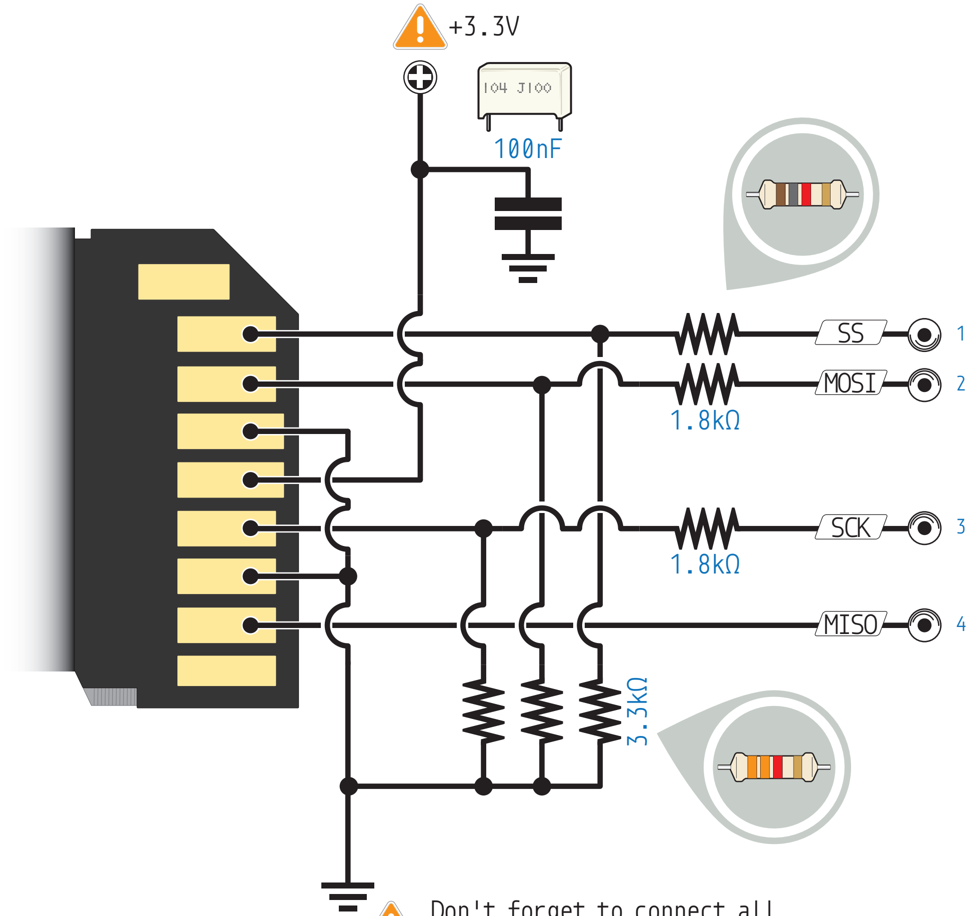
The Sharp GP2Y0A21 distance sensor is a popular choice for many projects that require accurate distance measurements, it has a measuring range of 10 to 80cm (4 to 32in). The relationship between the output voltage and the inverse of the measured distance is nonlinear and needs to be linearized in the code.

0-1.es/79

79

DIY microSD Card Reader

Basic Connections

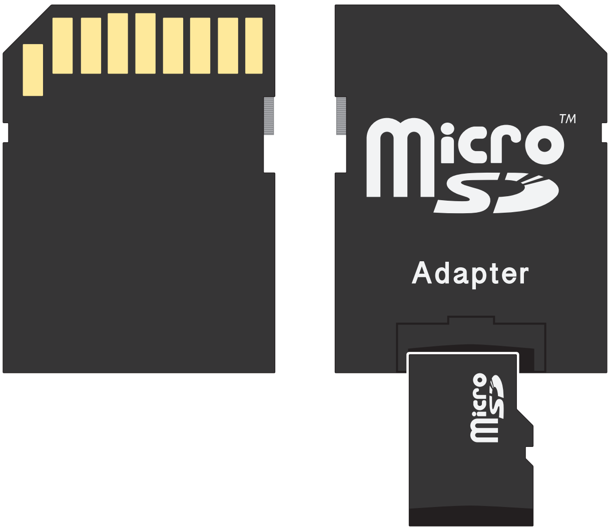


Don't forget to connect all the ground wires together!

microSD to SD card adapters come bundled with many microSD cards nowadays. You can build this circuit to convert that adapter into a microSD card reader for your microcontroller board.

0-1.es/79

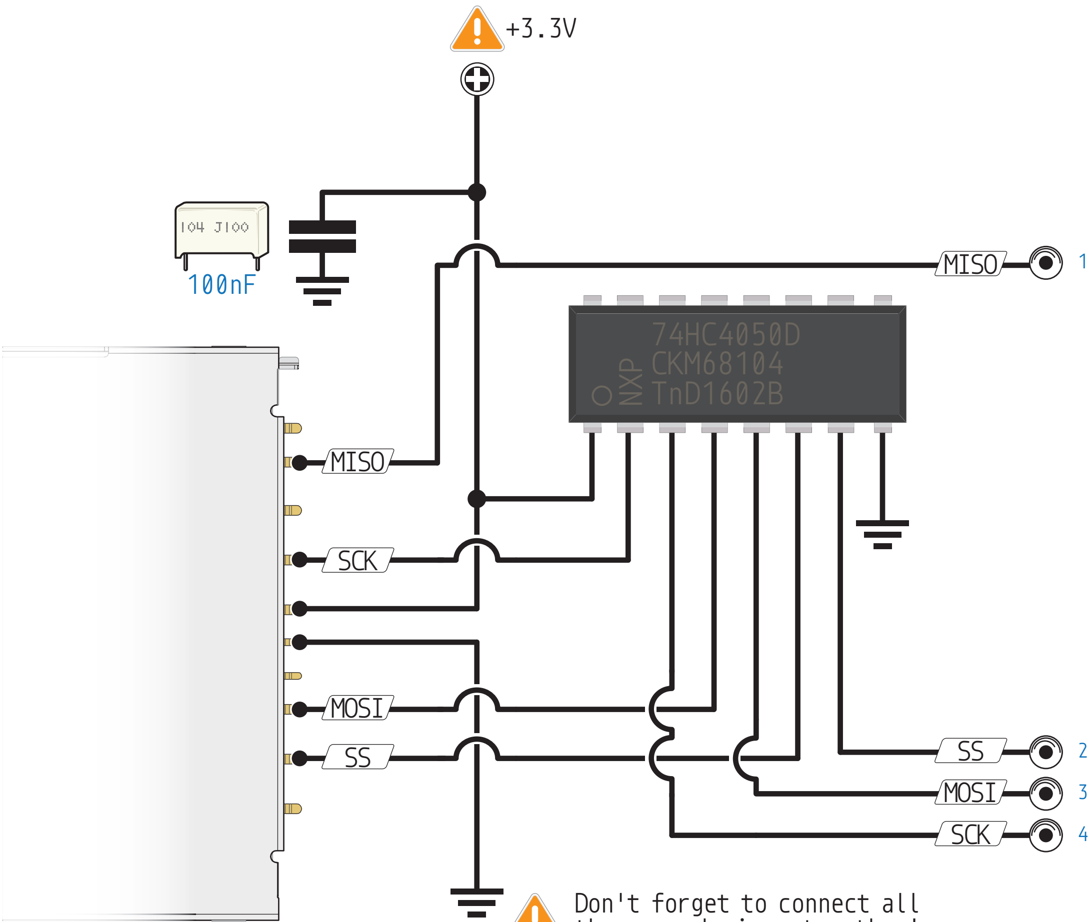
SD Card
Pinout



0-1.es/80

SD Card

Using the 4050 Buffer



Don't forget to connect all the ground wires together!

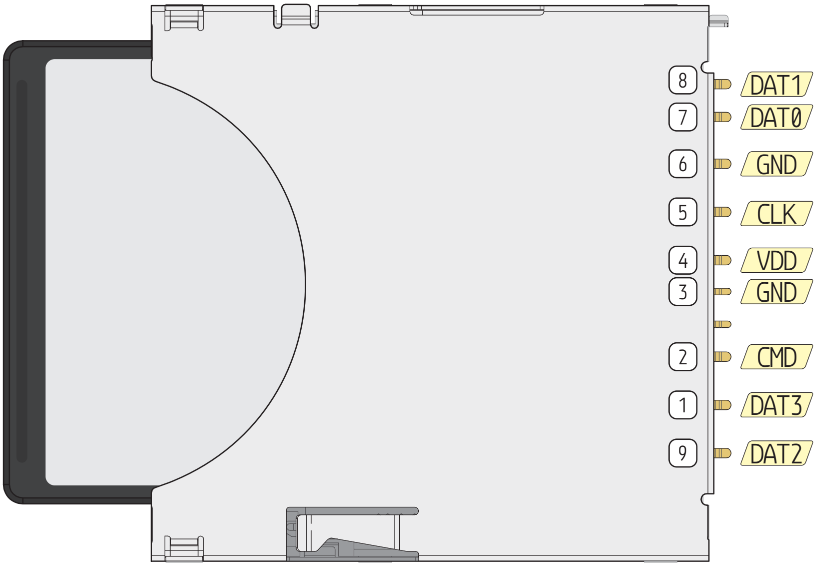
If you want to have a more professional, reliable and faster SD card reader you can opt for building this circuit using the 4050 buffer/converter instead of the DIY SD card reader circuit.

80

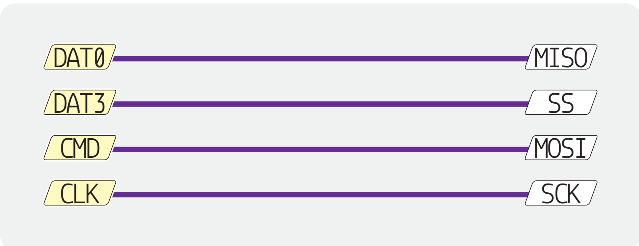
0-1.es/80

SD Card Socket

Pinout



Top view

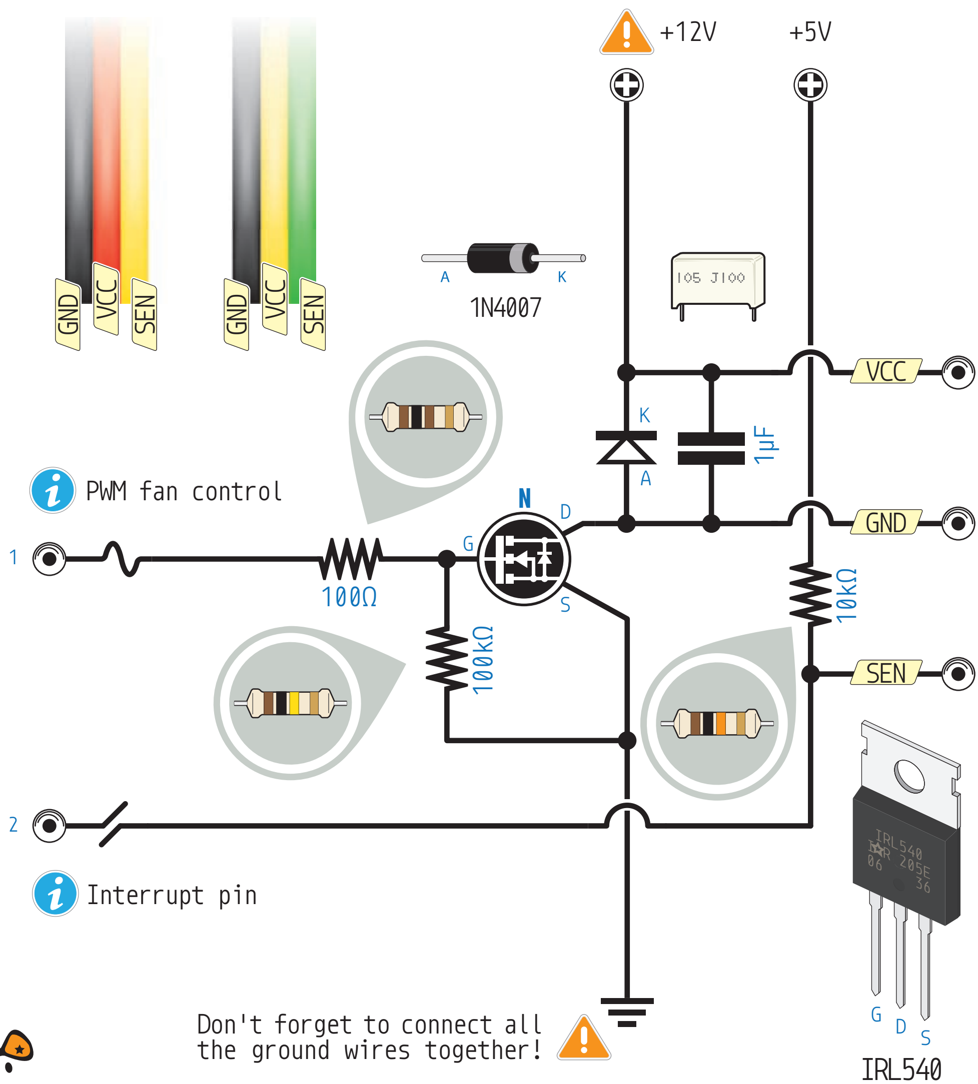


0-1.es/81

81

3-Wire Computer Fan

Basic Connections



PWM fan control

Interrupt pin

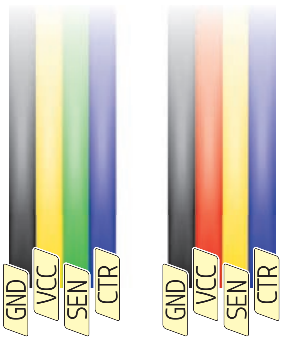
Don't forget to connect all the ground wires together!

82

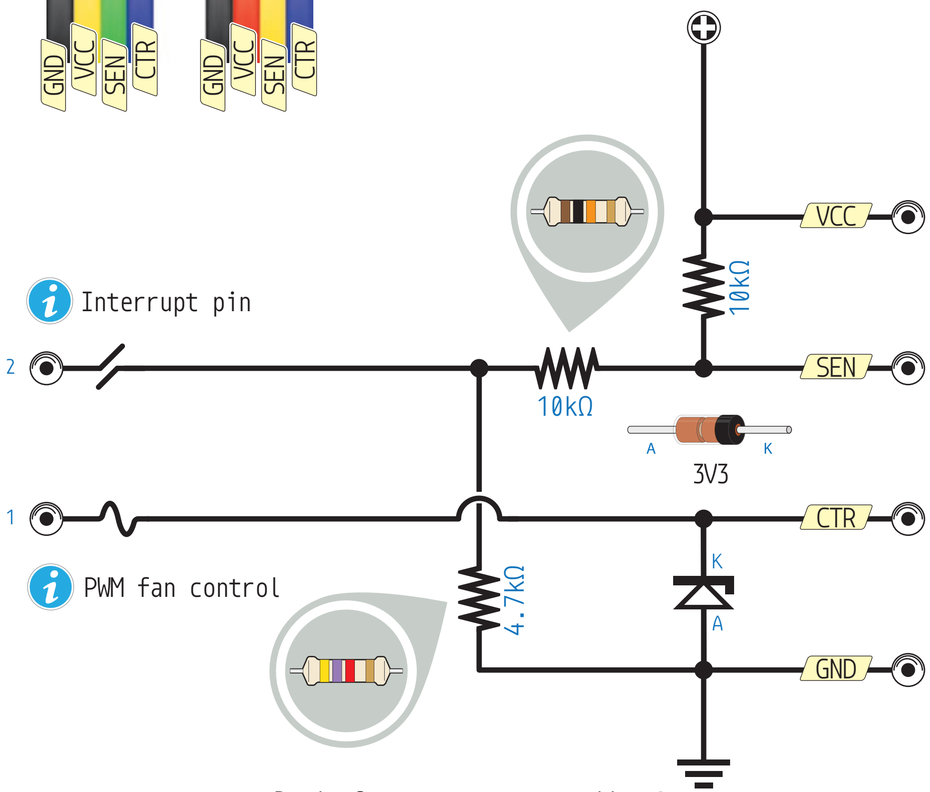
0-1.es/82

4-Wire Computer Fan

Basic Connections



PWM operating range 21kHz to 28kHz



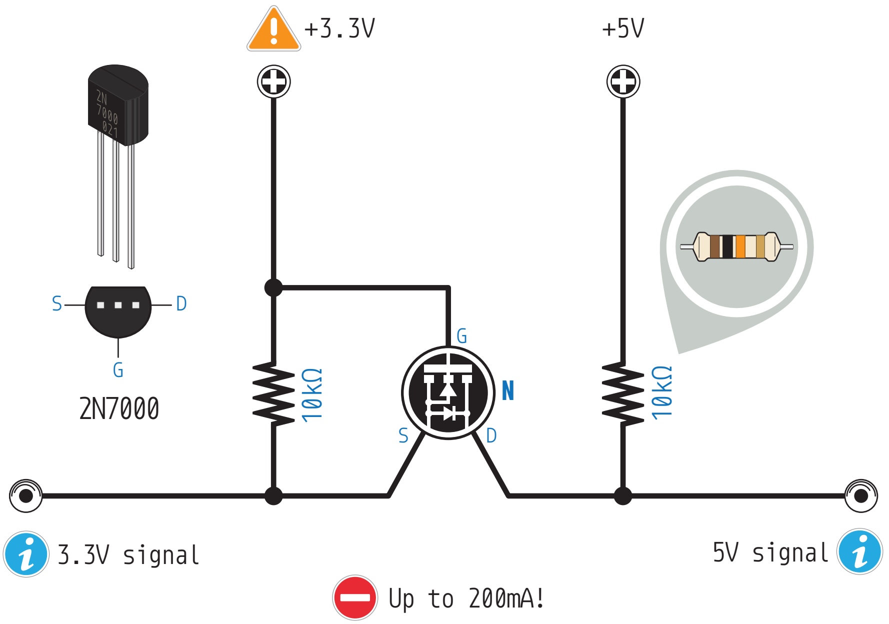
Don't forget to connect all
the ground wires together!

0-1.es/83

83

Bi-Directional Level Converter

Basic Connections



Don't forget to connect all the ground wires together!

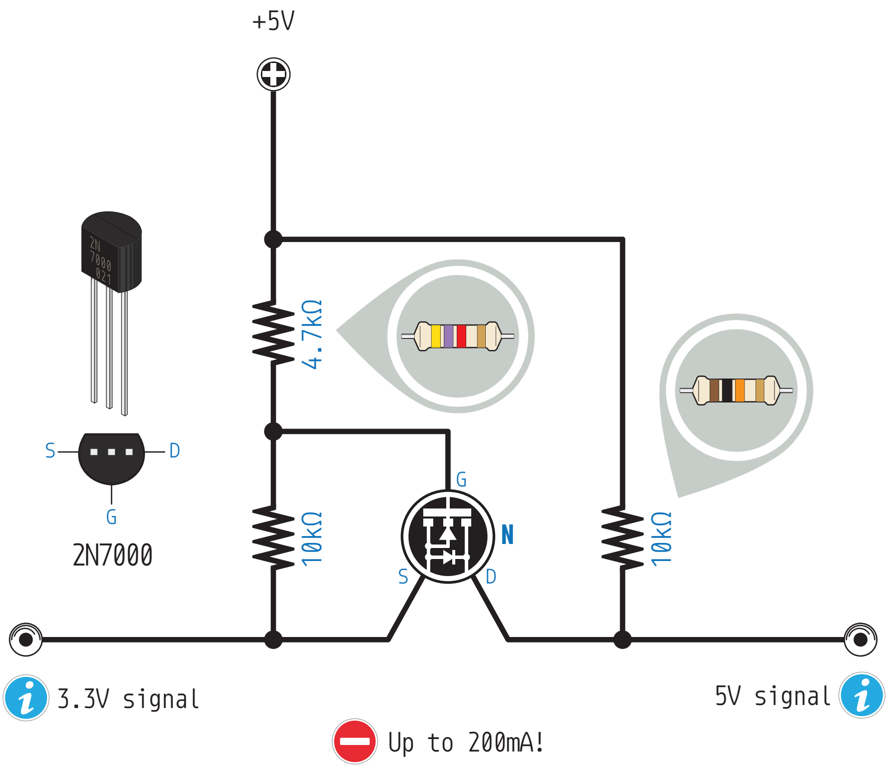
Bi-directional logic level converters allow you to connect devices that use 3.3V logic level signals to microcontroller boards that use 5V, and vice versa. You can use both 3.3V and 5V supply voltages for this circuit or use only the 5V supply and a voltage divider to obtain 3.3V.

83

0-1.es/83

Bi-Directional Level Converter

Voltage Divider Connections



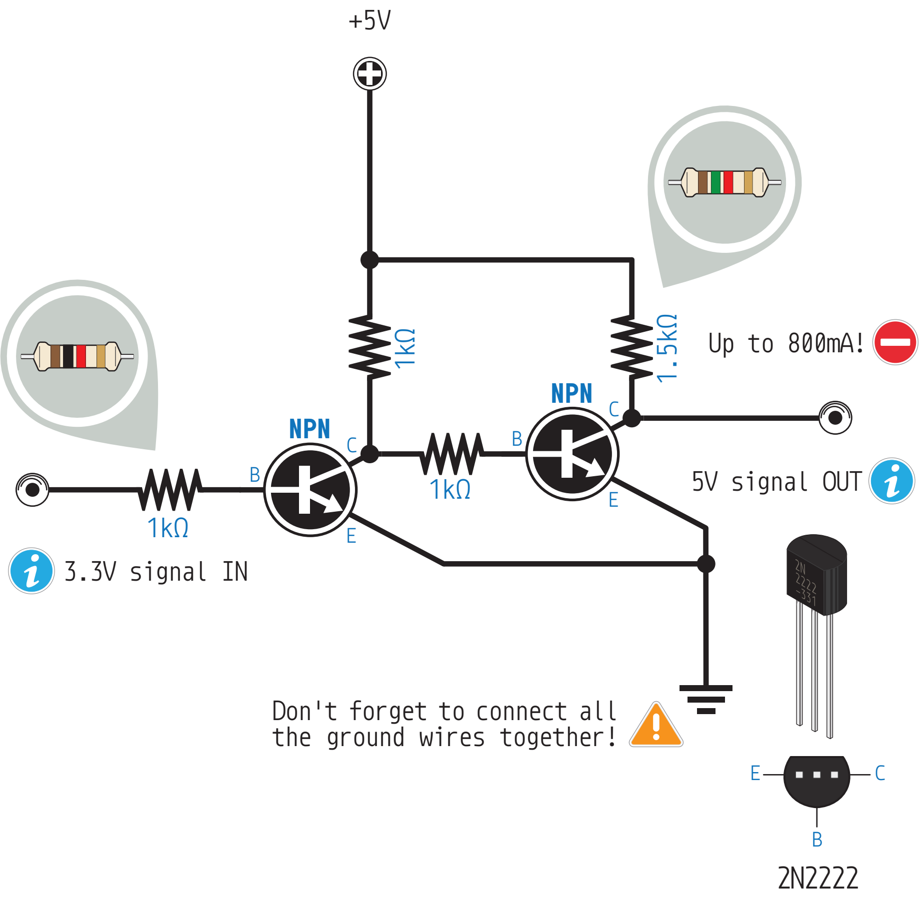
Don't forget to connect all
the ground wires together!

0-1.es/84

84

3.3V to 5V Level Shifter

Basic Connections



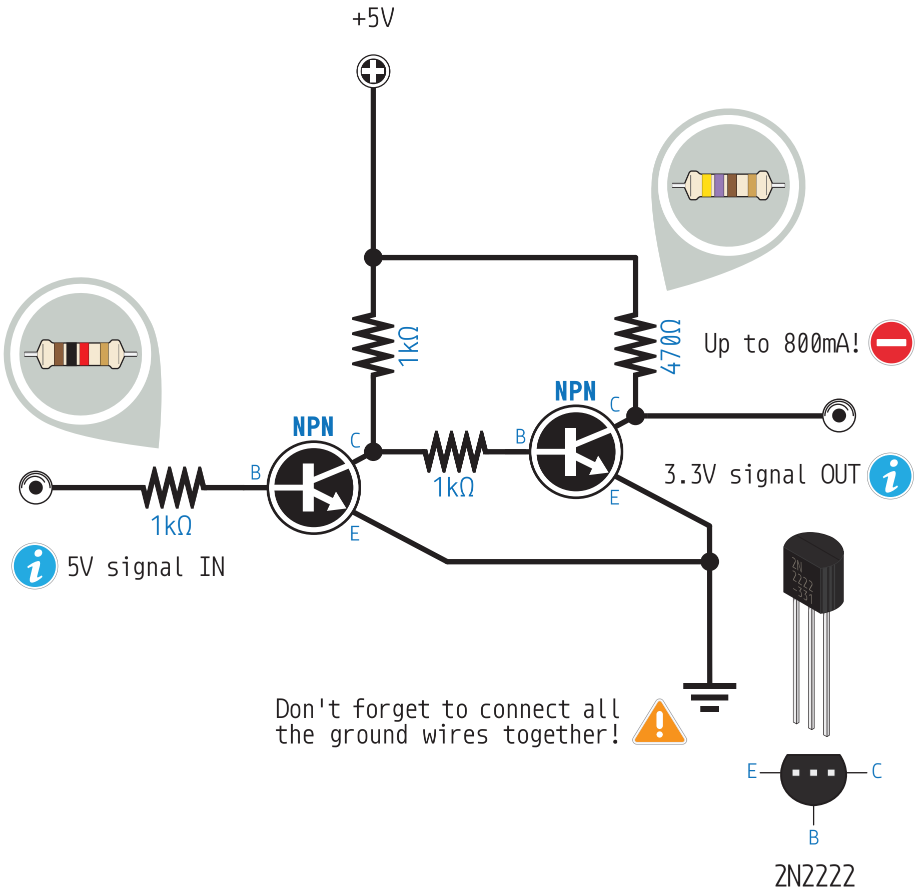
Logic level shifters allow you to connect devices that use 3.3V logic level signals to microcontroller boards that use 5V, or vice versa, depending on the circuit you build. Logic level shifters only allow for the signal to go from one particular logic level to another. Select the circuit according to your needs.

84

0-1.es/84

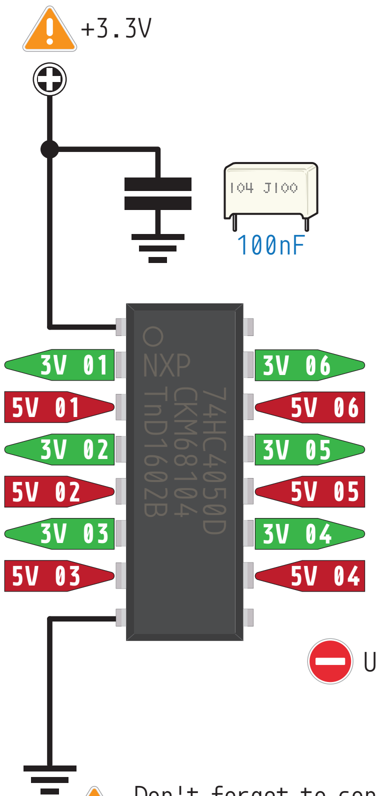
5V to 3.3V Level Shifter

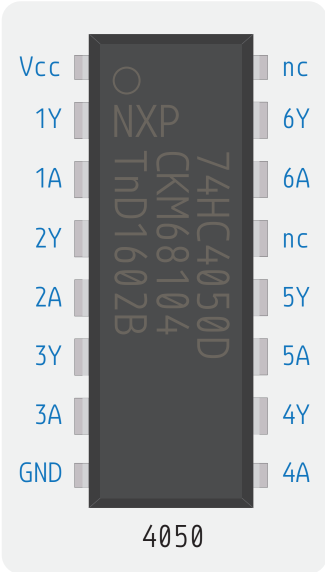
Basic Connections



4050 Level Shifter

Pinout





Up to 20mA per I/O pin!

Don't forget to connect all the ground wires together!

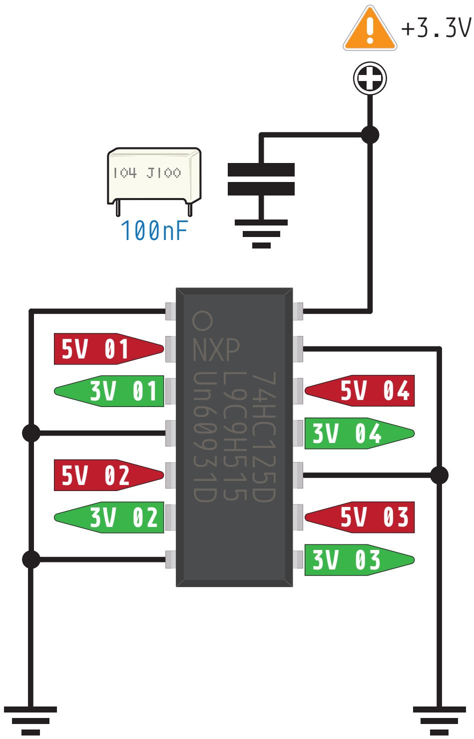
The 4050 is a hex buffer with over-voltage tolerant inputs. Inputs are overvoltage tolerant to up to 15V, which enables the device to be used in HIGH-to-LOW level shifting applications. The “hex” part means there’s actually six separate buffers in one chip.

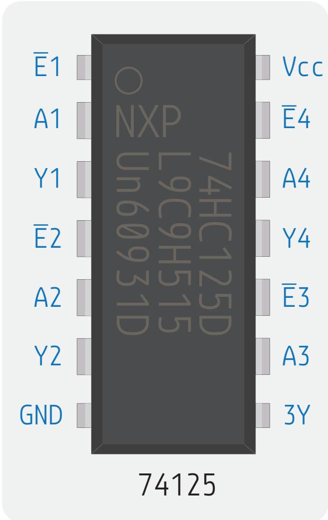
86

0-1.es/86

74125 Level Shifter

Pinout





Up to 35mA per I/O pin!

Don't forget to connect all the ground wires together!

The 74125 is a quad buffer/line driver with 3-state outputs controlled by the output enable inputs (E). A HIGH on E pin causes the outputs to assume a high-impedance OFF state. The “quad” part means there’s actually four separate buffers/line driver in one chip.

0-1.es/87

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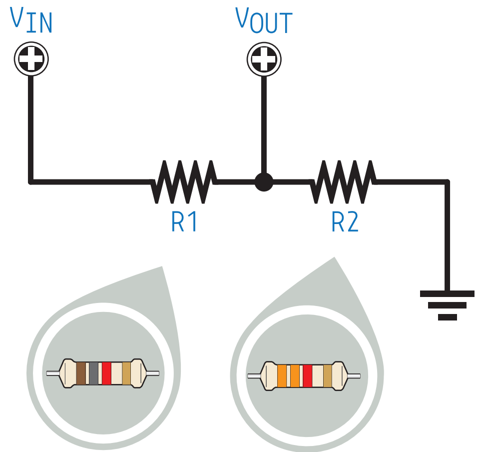
Voltage Divider

Theory



FORMULA

$$V_{OUT} = V_{IN} \times R2 \,/\, (R1 + R2)$$

$$V_{OUT} = 5V \times 3.3k\Omega \,/\, (1.8k\Omega + 3.3k\Omega)$$

$$V_{OUT} = 3.2V$$

A voltage divider is a simple circuit that produces an output voltage that is a fraction of its input voltage by using just two series resistors. Voltage dividers are one of the most fundamental circuits in electronics.

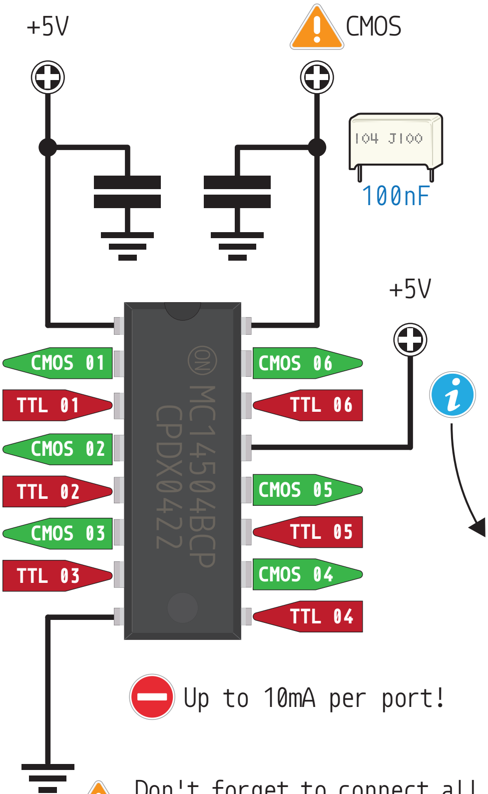
88

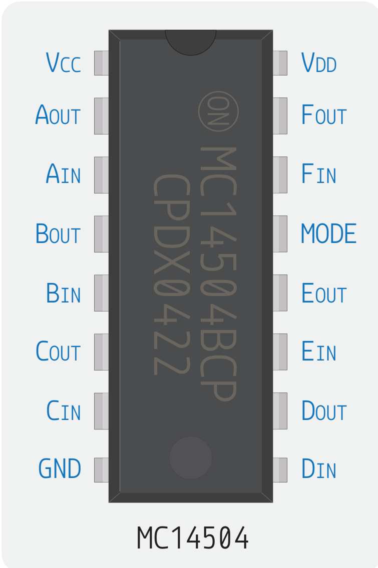
0-1.es/88

TTL-CMOS Level Shifter

Using the MC14504

3V to 18V operation for V_{DD} and V_{CC}





Mode select	Input logic levels	Output logic levels
1 (V_{CC})	**TTL**	**CMOS**
2 (V_{DD})	**CMOS**	**CMOS**

Up to 10mA per port!

Don't forget to connect all the ground wires together!

The MC14504x is a hex non-inverting level shifter using CMOS technology. The level shifter will shift a TTL signal to CMOS logic levels for any CMOS supply voltage between 5 and 15 volts. A control input also allows interface from CMOS to CMOS at one logic level to another logic level.

0-1.es/89

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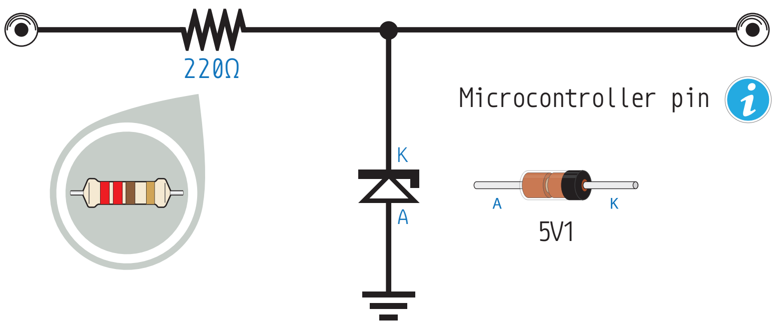
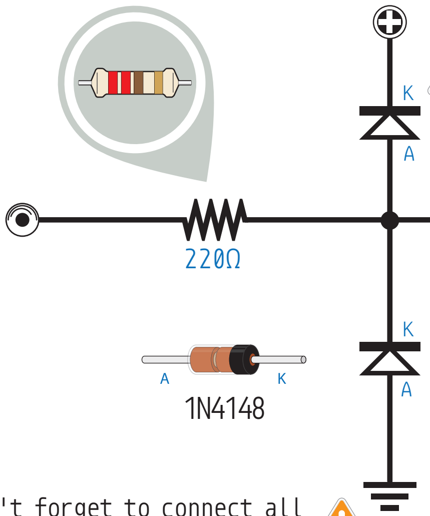
I/O Pin Protection

Using a Zener Diode



Using Clamping Diodes



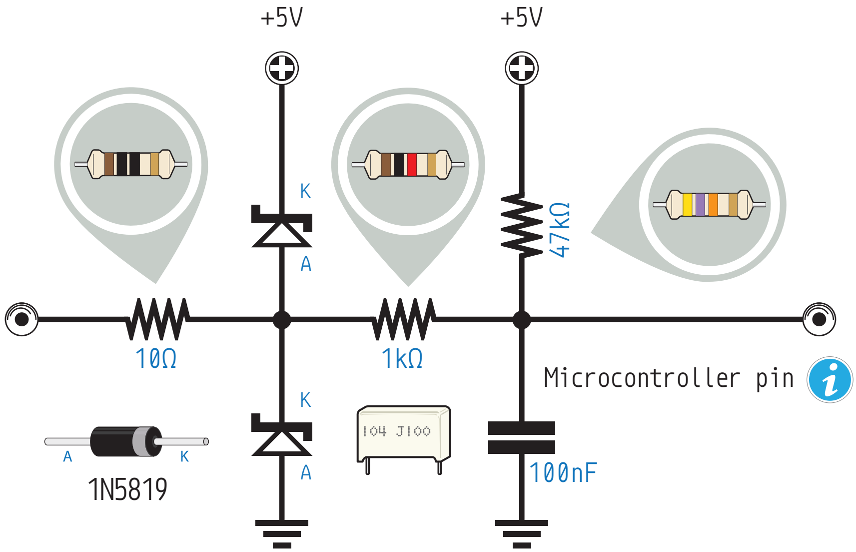
If you want the limit value to be closer to 5.2 V rather than 5.7V use Schottky diodes instead of regular silicon diodes

Don't forget to connect all the ground wires together!

0-1.es/90

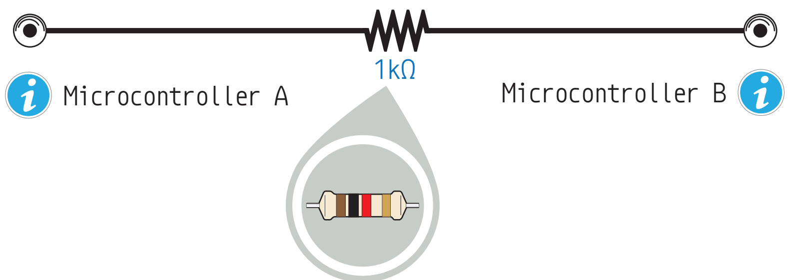
I/O Pin Filtering & Protection

Basic Connections



Two Microcontroller Boards

Basic Connections



Don't forget to connect all
the ground wires together!

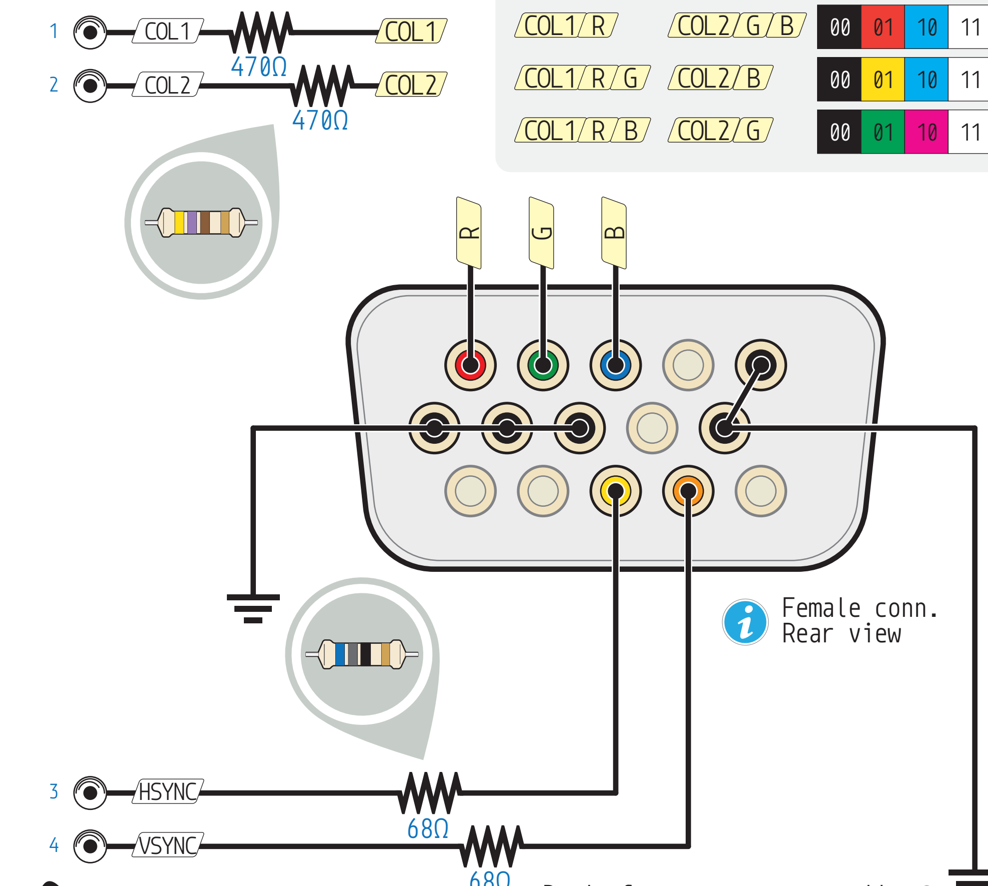
0-1.es/91

91

VGA Output

Basic Connections

COL1/R	COL2/G	00	01	10	11
COL1/R	COL2/B	00	01	10	11
COL1/G	COL2/B	00	01	10	11
COL1/R	COL2/G/B	00	01	10	11
COL1/R/G	COL2/B	00	01	10	11
COL1/R/B	COL2/G	00	01	10	11



Don't forget to connect all the ground wires together!

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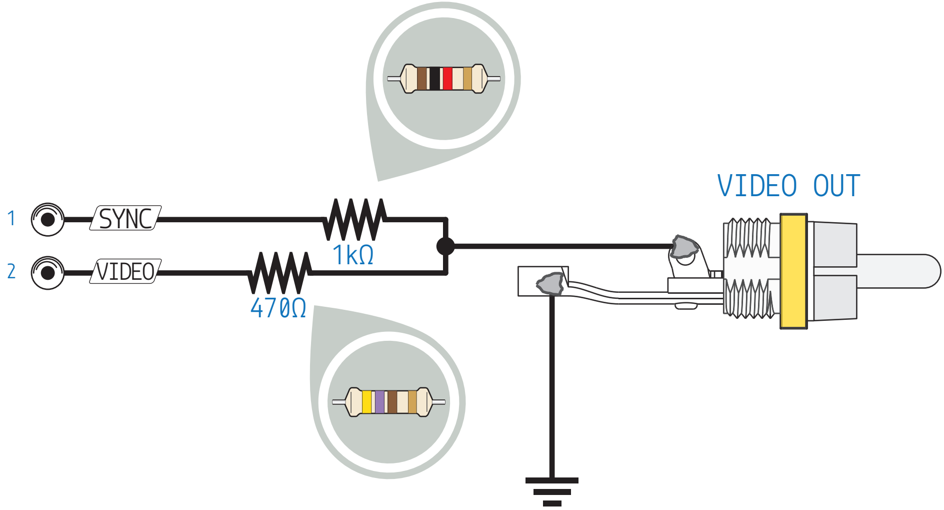
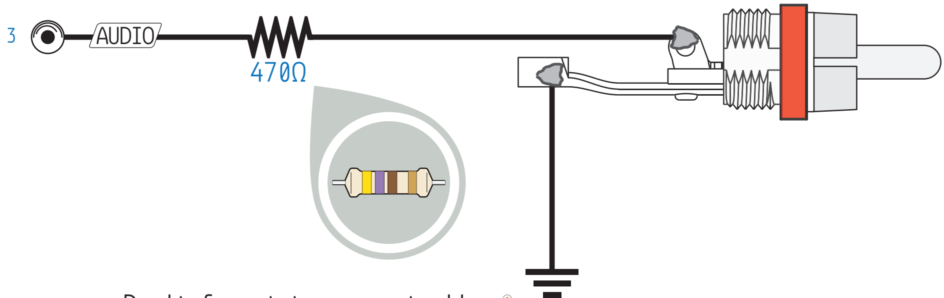
0-1.es/92

Composite Output

Basic Connections



75Ω resistor required between VIDEO and GND on the RCA plug for a very small subset of TVs



Don't forget to connect all the ground wires together!

0-1.es/93

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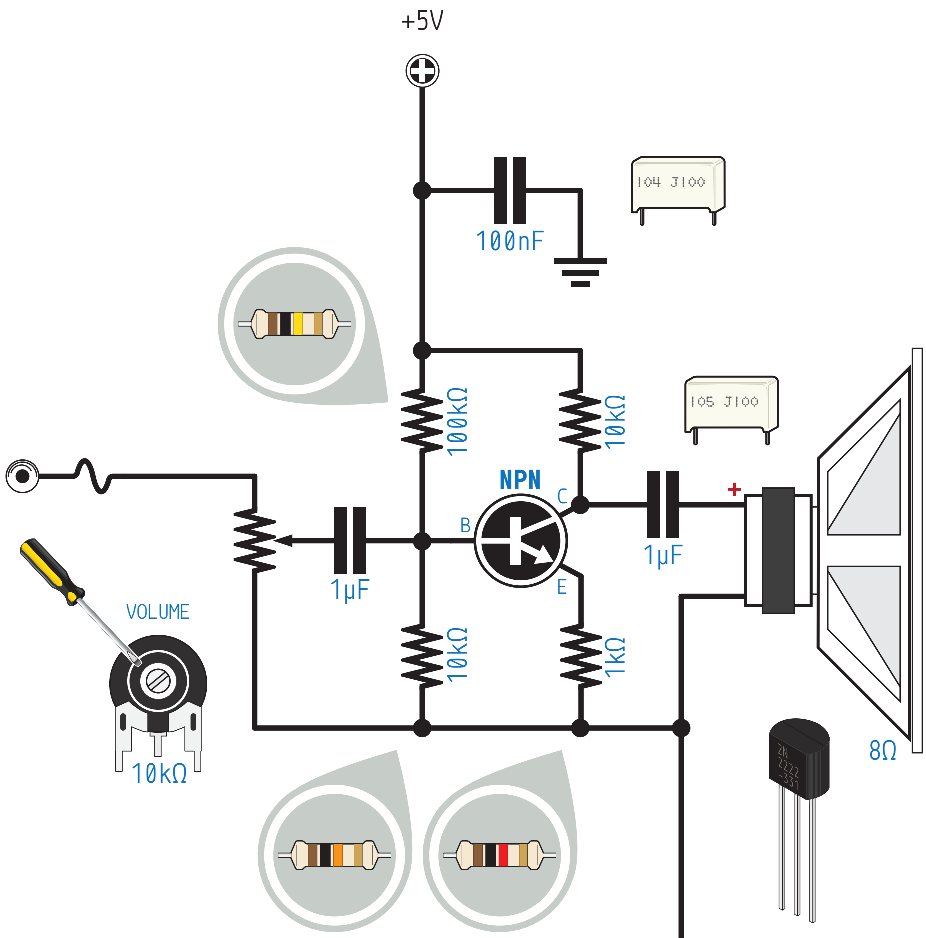
Single-Transistor Amplifier

Basic Connections



Don't forget to connect all the ground wires together!

2N2222

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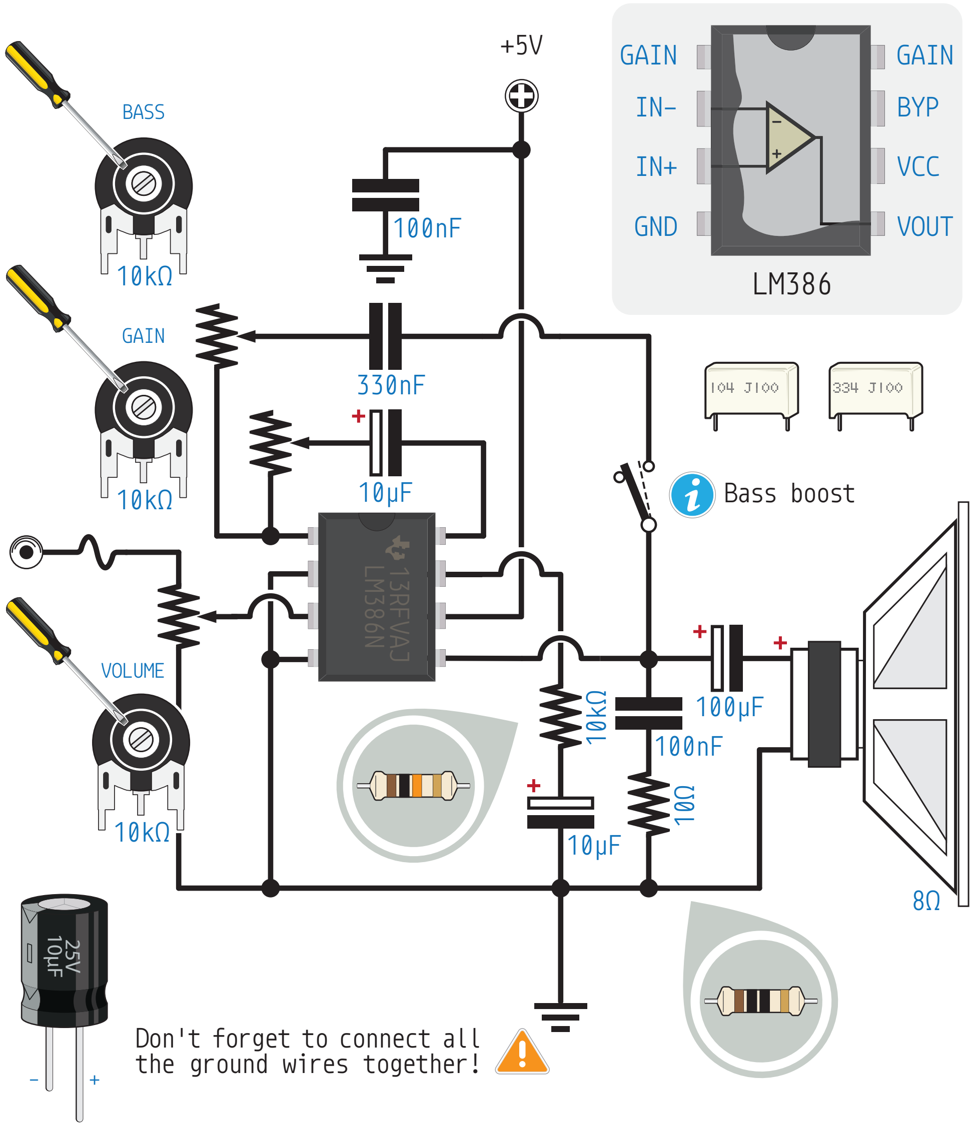
0-1.es/94

Audio Amplifier

Using the LM386 Audio Amplifier



Don't forget to connect all the ground wires together!

0-1.es/95

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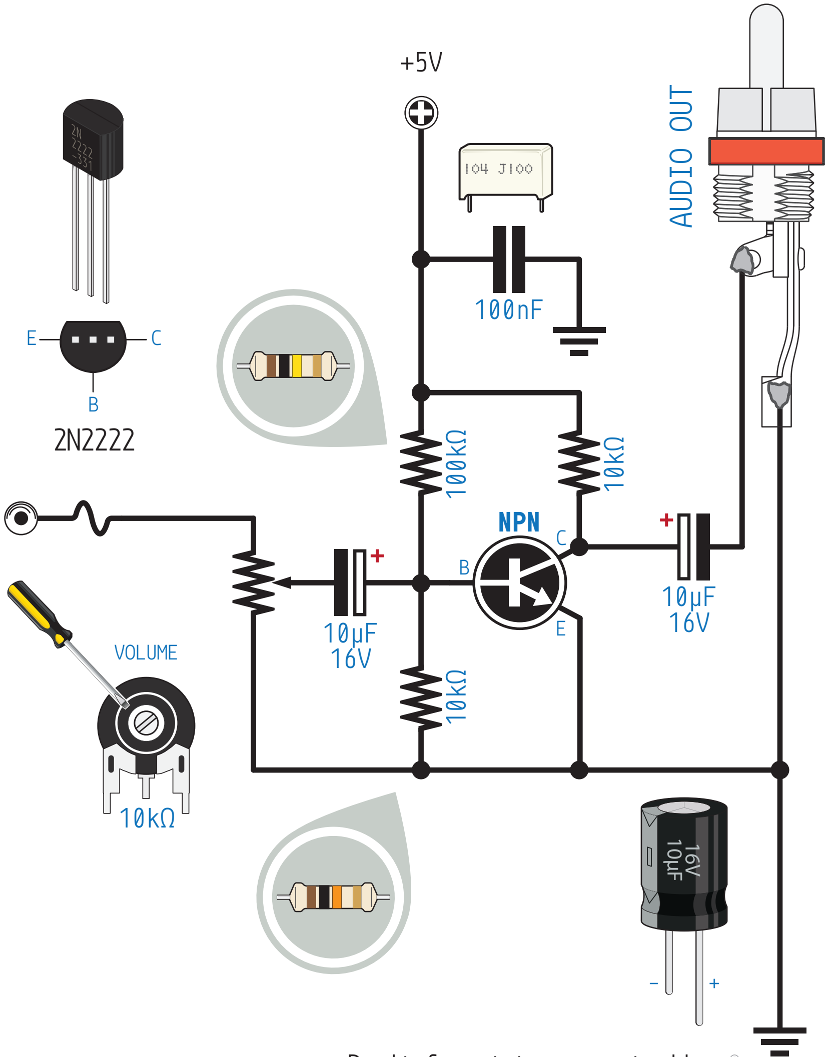
Preamplifier

Basic Connections



Don't forget to connect all the ground wires together!

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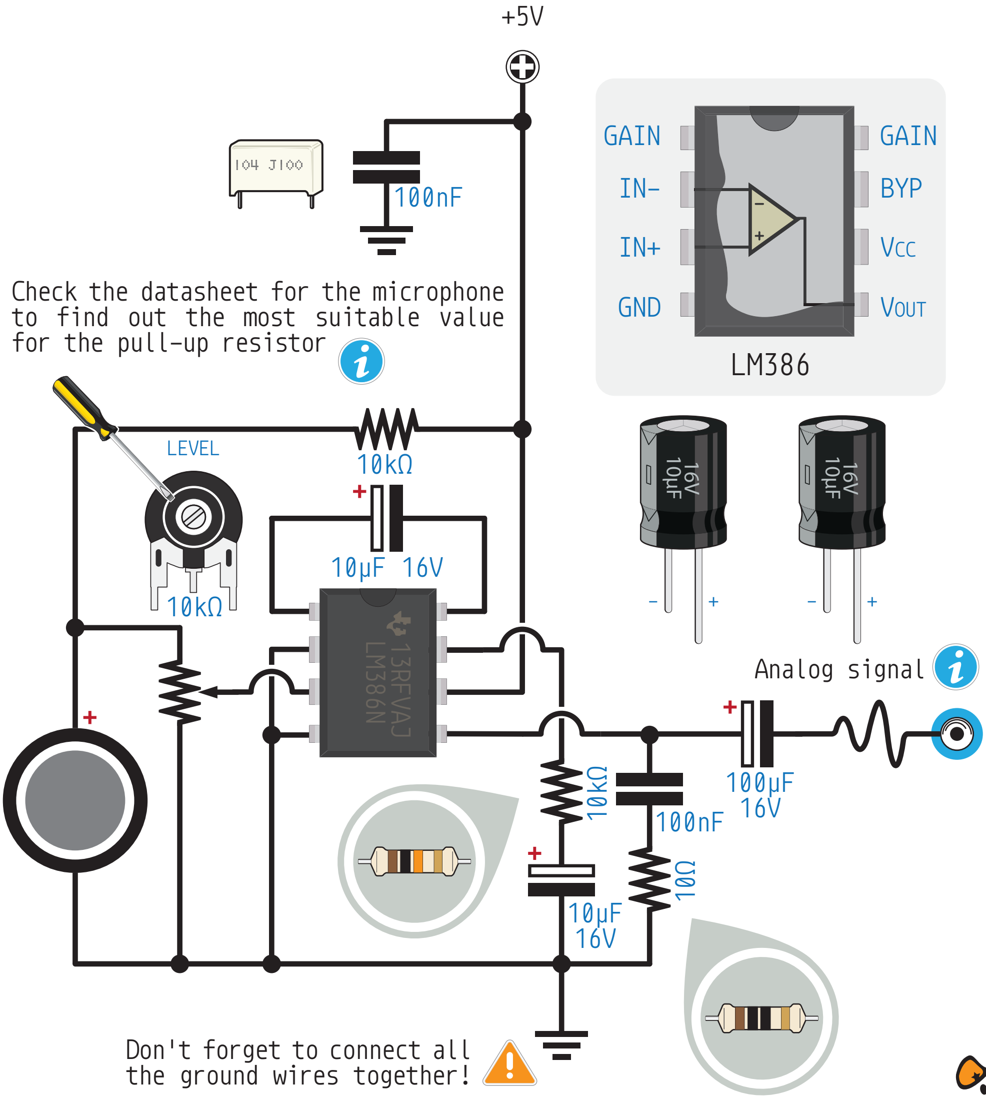
0-1.es/96

Microphone

Using the LM386 Audio Amplifier



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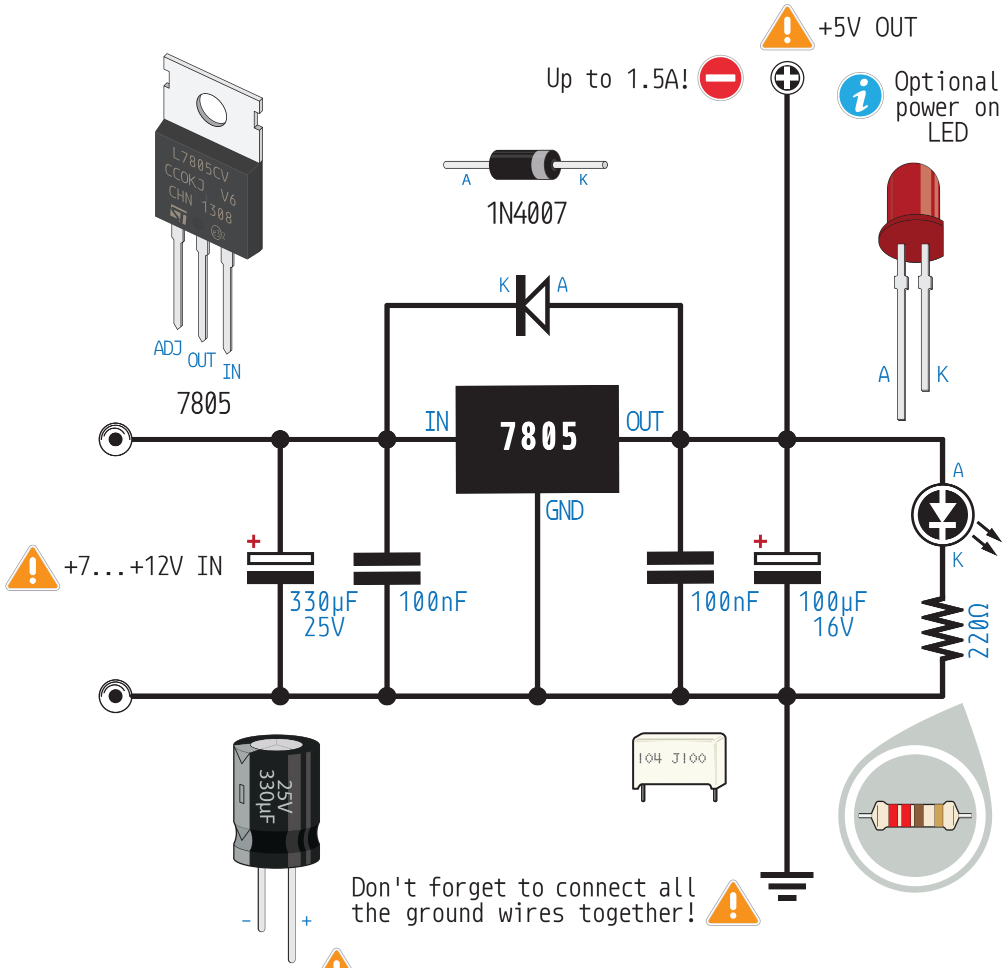
Simple 5V Power Supply

Basic Connections



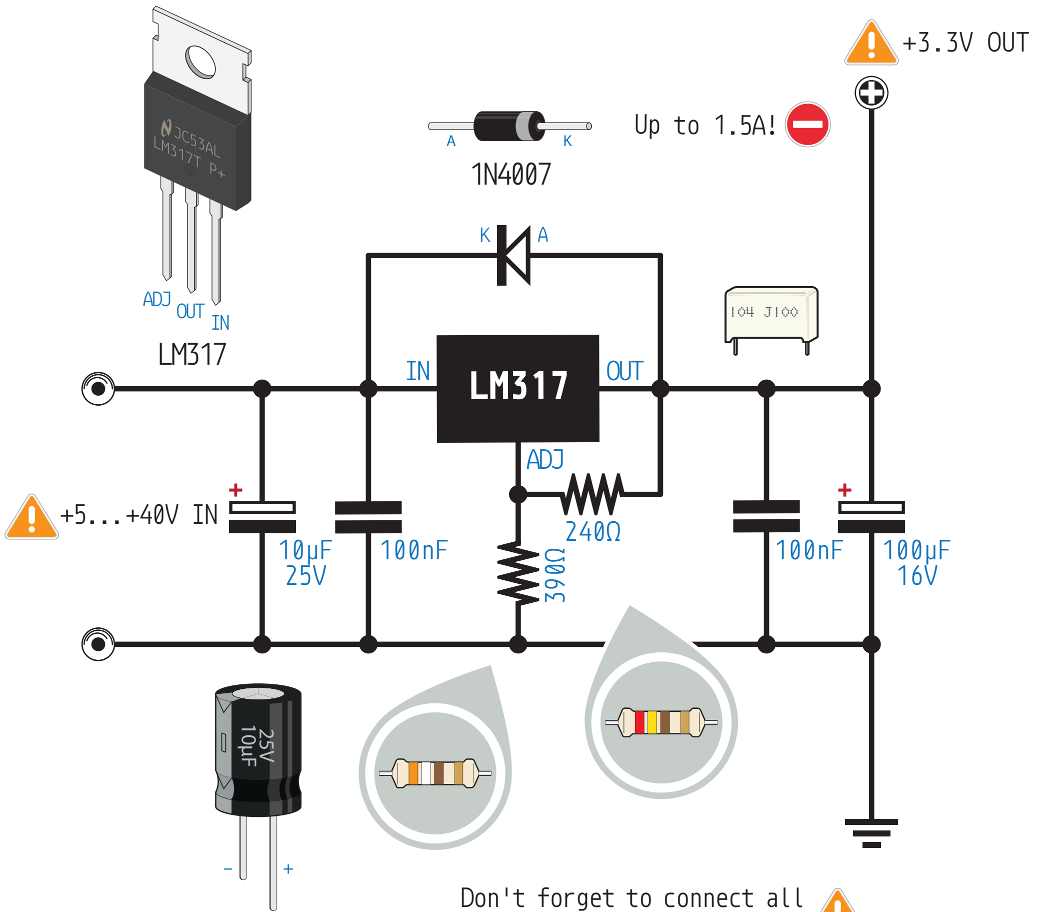
Don't forget to attach a heat sink to the 7805 if are connecting a high-power load!

98

0-1.es/98

Simple 3.3V Power Supply

Basic Connections



Don't forget to connect all the ground wires together!

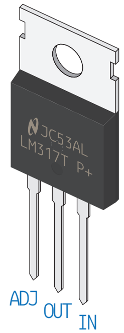
Don't forget to attach a heat sink to the LM317 if are connecting a high-power load!

0-1.es/99

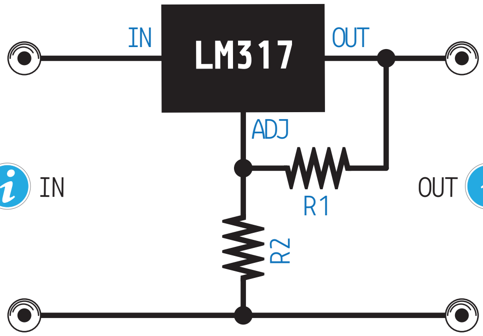
99

Simple Adjustable Power Supply

Using the LM317 Voltage Regulator

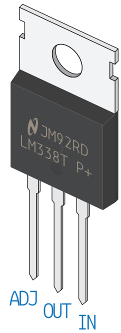


LM317



IN

OUT



LM338

Up to 1.5A!

Up to 5A!

You can use a trimmer instead of R1 and R2 to adjust the output voltage manually

$$V_{OUT} = 1.25 \times (1 + (R2 / R1))$$

$$V_{OUT} = 1.25 \times (1 + (390 / 240))$$

$$V_{OUT} = 3.28V$$

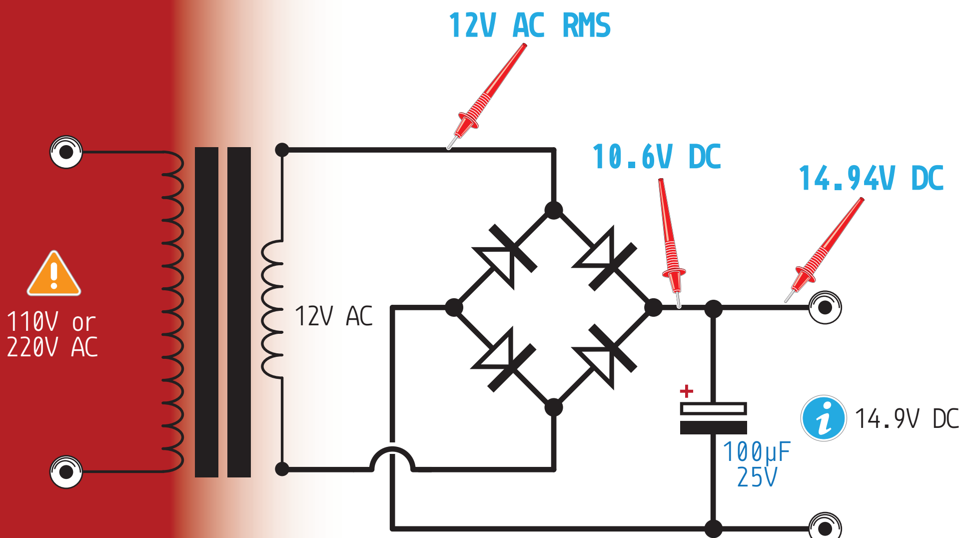
V_{OUT}	R1	R2
3.3V	**240Ω**	**390Ω**
5V	**240Ω**	**750Ω**
6V	**240Ω**	**1kΩ**
9V	**240Ω**	**1.5Ω**

100

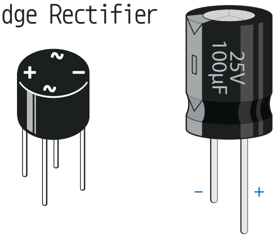
Full-Wave Rectifier

Basic Connections

0-1.es/100



Bridge Rectifier



When using a bridge rectifier and a capacitor

$$V_{OUT} = (V_{IN} - 1.4) \times 1.41$$

$$V_{OUT} = (12 - 1.4) \times 1.41$$

$$V_{OUT} = \mathbf{14.946V}$$

WARNING!

Mains voltage electricity is very dangerous. There is a high risk of death through electrocution if mains electricity is allowed to pass through your body, adding to the risk of fire or explosion if electricity is not cabled and fused correctly. NEVER connect mains voltage to a breadboard!

Use the instructions and suggestions in ABC: Basic Connections at your own risk. PighiXXX and the author disclaim all responsibility for any resulting damage, injury, or expense. It is your responsibility to make sure that your activities comply with the safety precautions.

WARNING!

Generally, dealing with voltages lower than 50V is relatively safe, but anything above that can be dangerous. Always make the proper connections with the wires disconnected from the power outlet. Isolation between wires and other parts of the circuit that work at lower voltages is crucial. Always use wires rated for the voltage and current applied to them. This also applies, specifically for current, for all circuits covered in this book.

Unless otherwise stated, do not connect DC signal ground (GND) and AC ground (earth) together!

0-1.es/101

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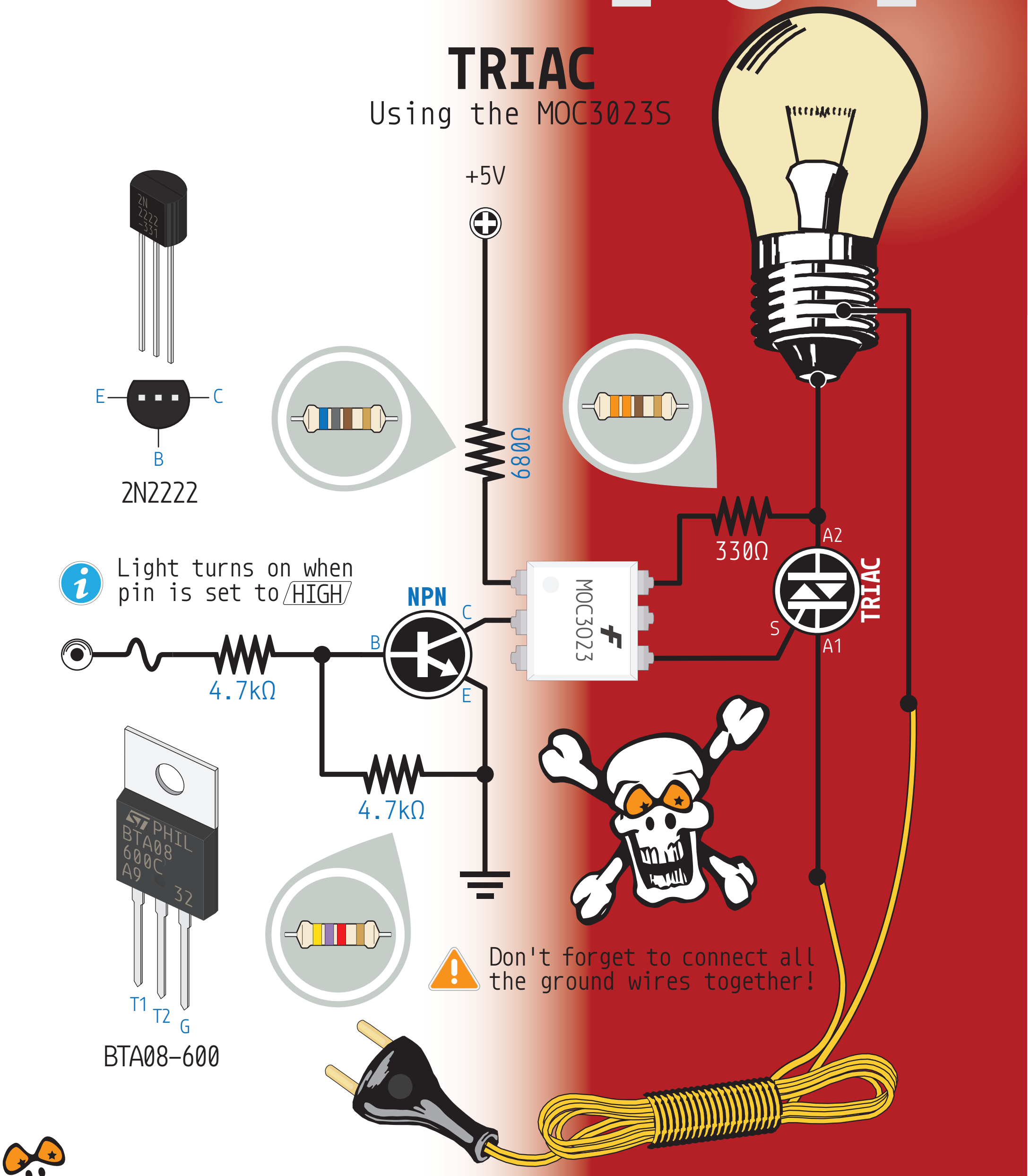
TRIAC

Using the MOC3023S



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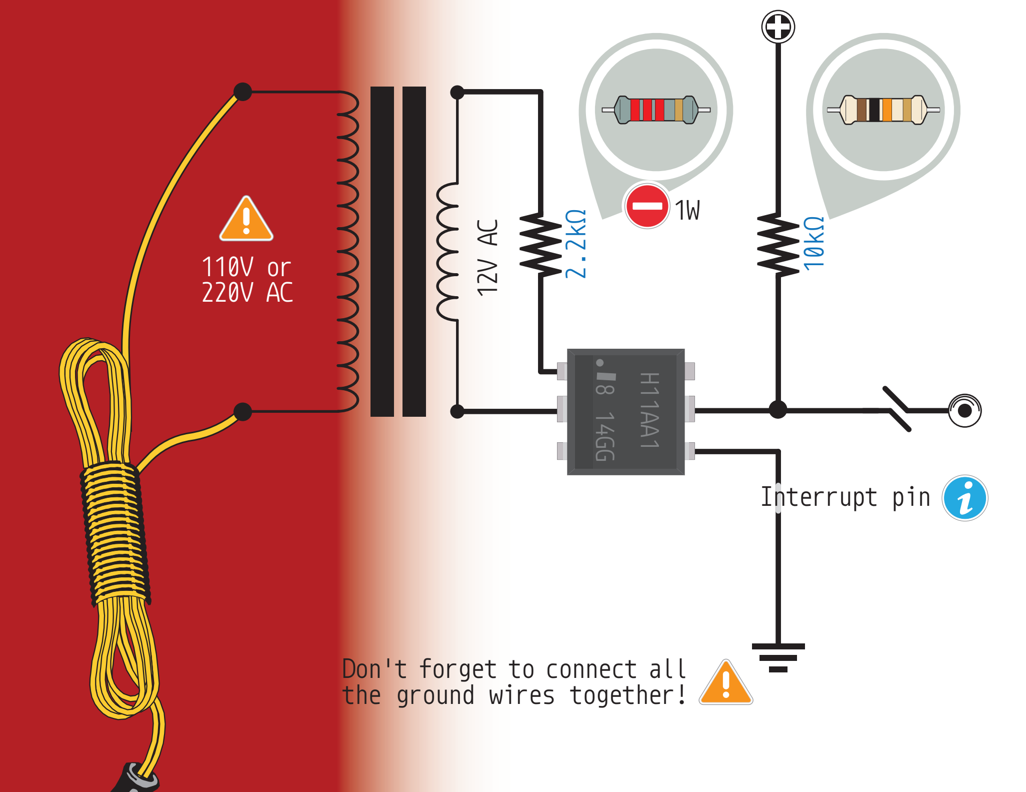
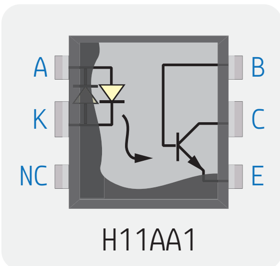
Zero-Crossing Detector

Using the H11AA1 Optocoupler





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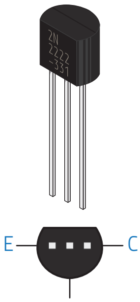
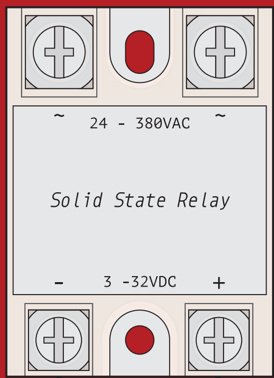
Solid-State Relay

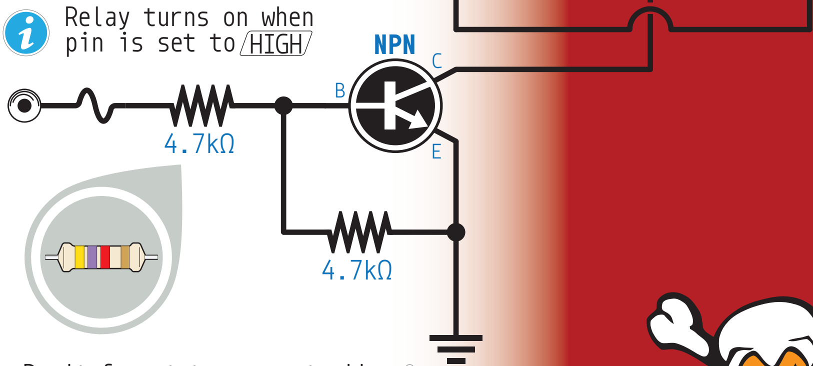
Basic Connections



2N2222



Relay turns on when pin is set to HIGH



Don't forget to connect all the ground wires together!

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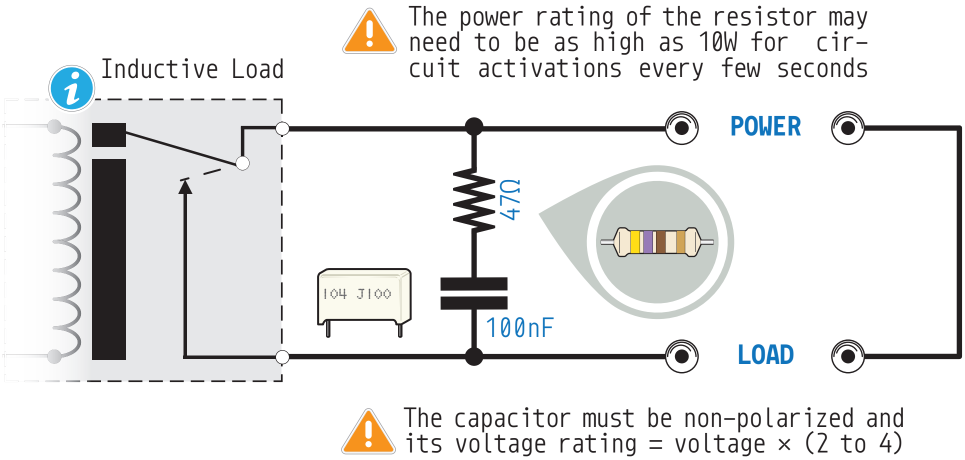
0-1.es/104

RC Snubber Network

Theory



FORMULA

$$C = \frac{I^2}{10} \qquad R(\Omega) = \frac{E}{10 \times I \times (I + \frac{50}{E})}$$

SIMPLE FORMULA

R(Ω) = voltage(V) × (.5 to 1)
C(µF) = current(A) × (.5 to 1)

Standard values are 47Ω for the resistor and 100nF for the capacitor

Snubbers are used in electrical systems with an inductive load where the sudden interruption of current flow leads to a sharp rise in voltage across the current switching device. A simple RC snubber uses a resistor and a capacitor in series to suppress a rapid rise in voltage.

0-1.es/105

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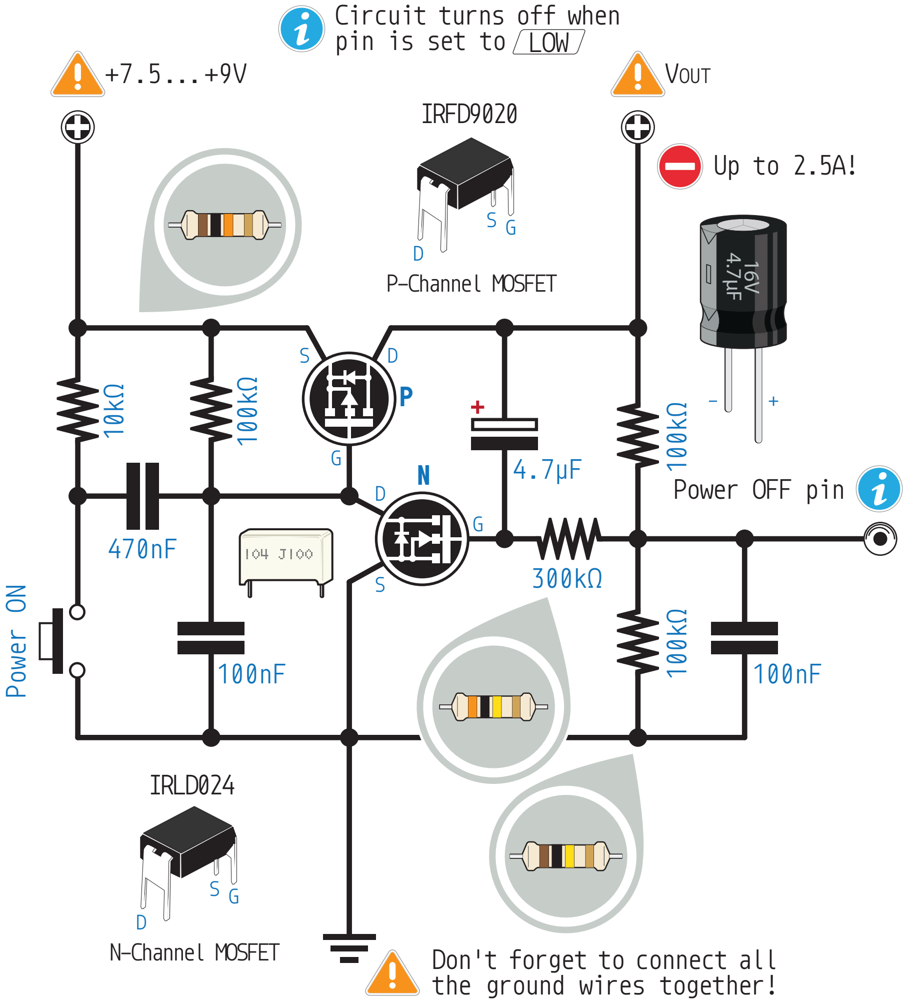
Soft Latching Power ON Switch

Basic Connections



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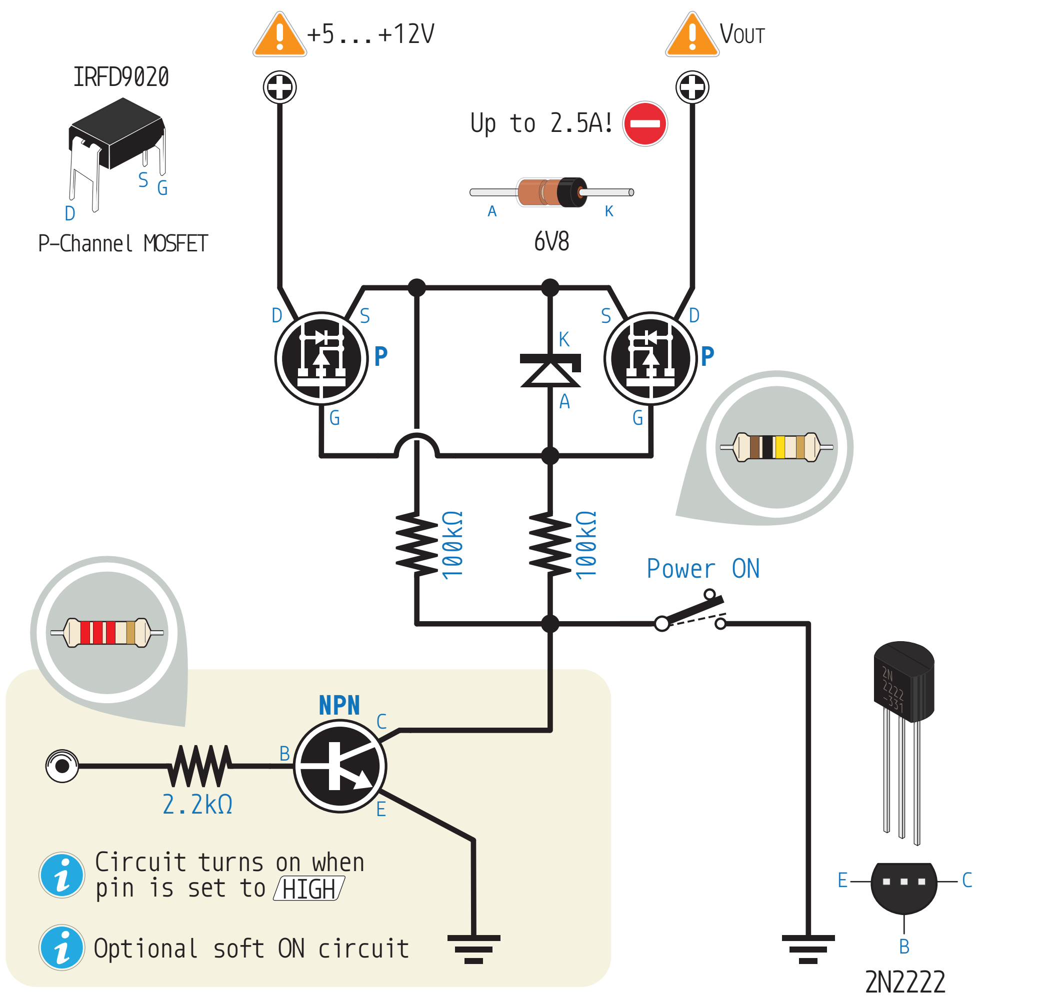
Reverse Voltage Protection

Basic Connections



Don't forget to connect all the ground wires together!

0-1.es/107

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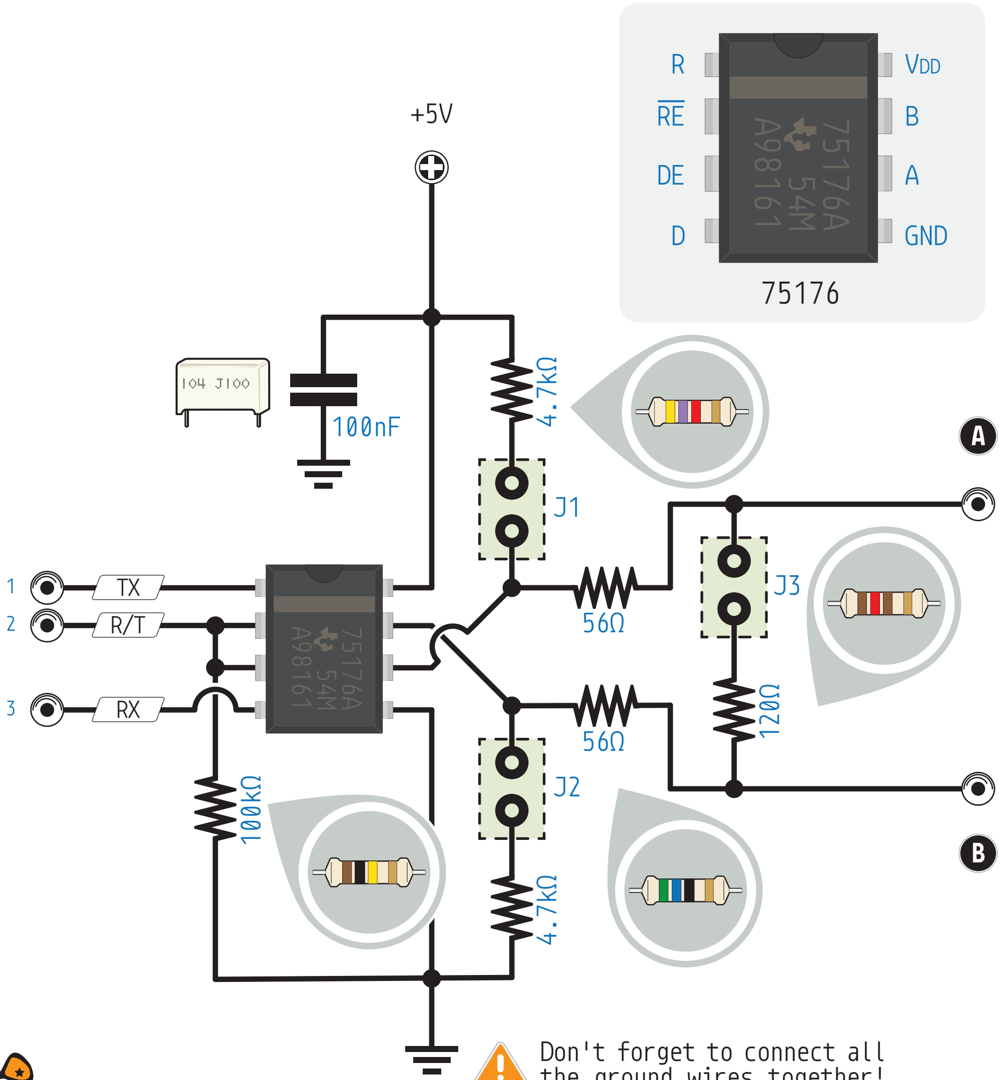
RS-485 Interface

RS-485 Node Using the 75176 Transceiver



Don't forget to connect all the ground wires together!

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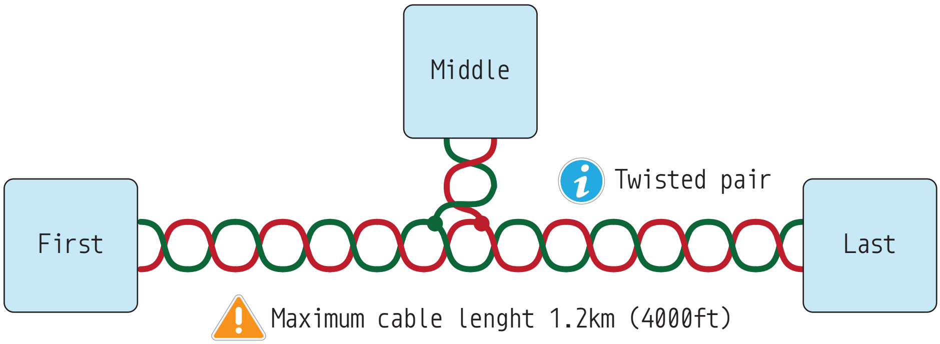
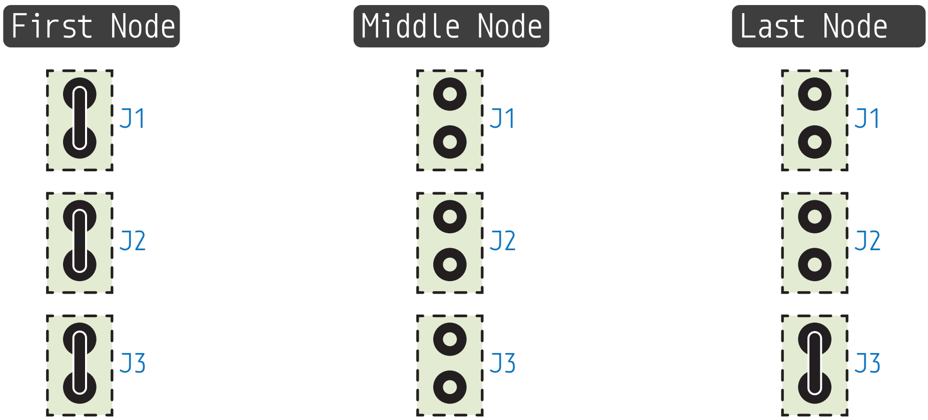
RS-485 Interface

Node Termination Jumpers





Maximum number of drivers and receivers per line: 32

RS-485 is a standard for serial communication transmission of data, especially useful to transmit data over long distances and in electrically noisy environments. Typical applications are process automation (chemicals, brewing, paper mills), factory automation, security, and motor control.

0-1.es/108

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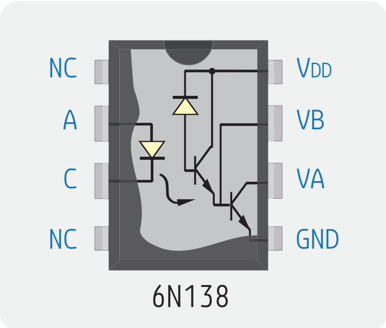
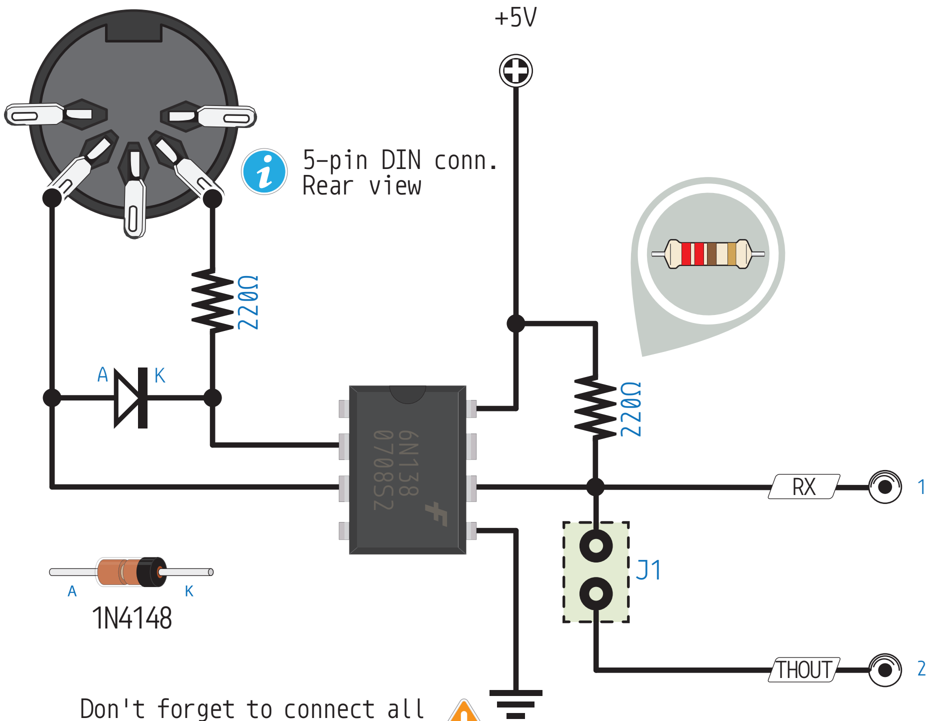
MIDI IN

Using the 6N138 Optocoupler



Short J1 to copy data stream from the input to the THRU port



Don't forget to connect all the ground wires together!

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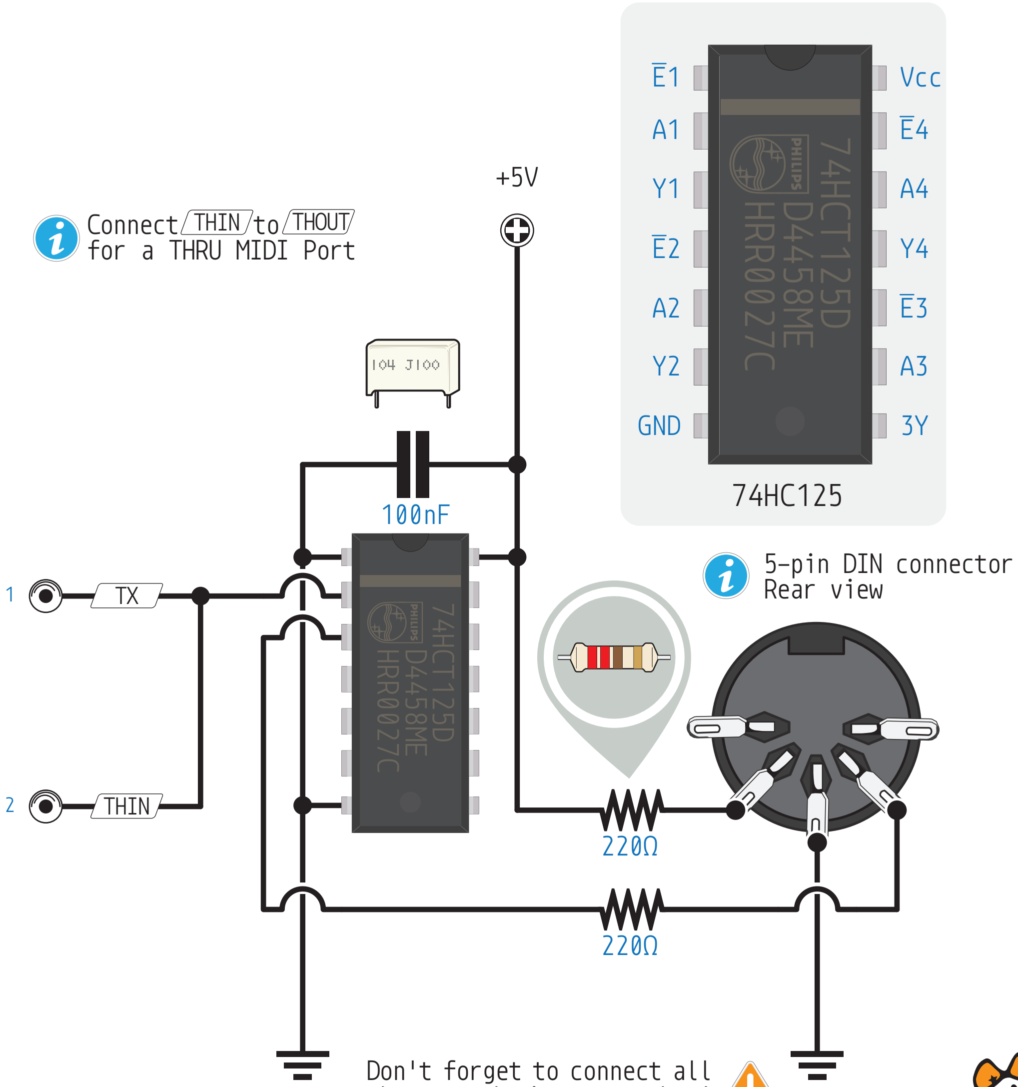
0-1.es/109

MIDI OUT

Using the 74HCT125 Bus Buffer

Connect THIN to THOUT for a THRU MIDI Port

5-pin DIN connector Rear view



Don't forget to connect all the ground wires together!

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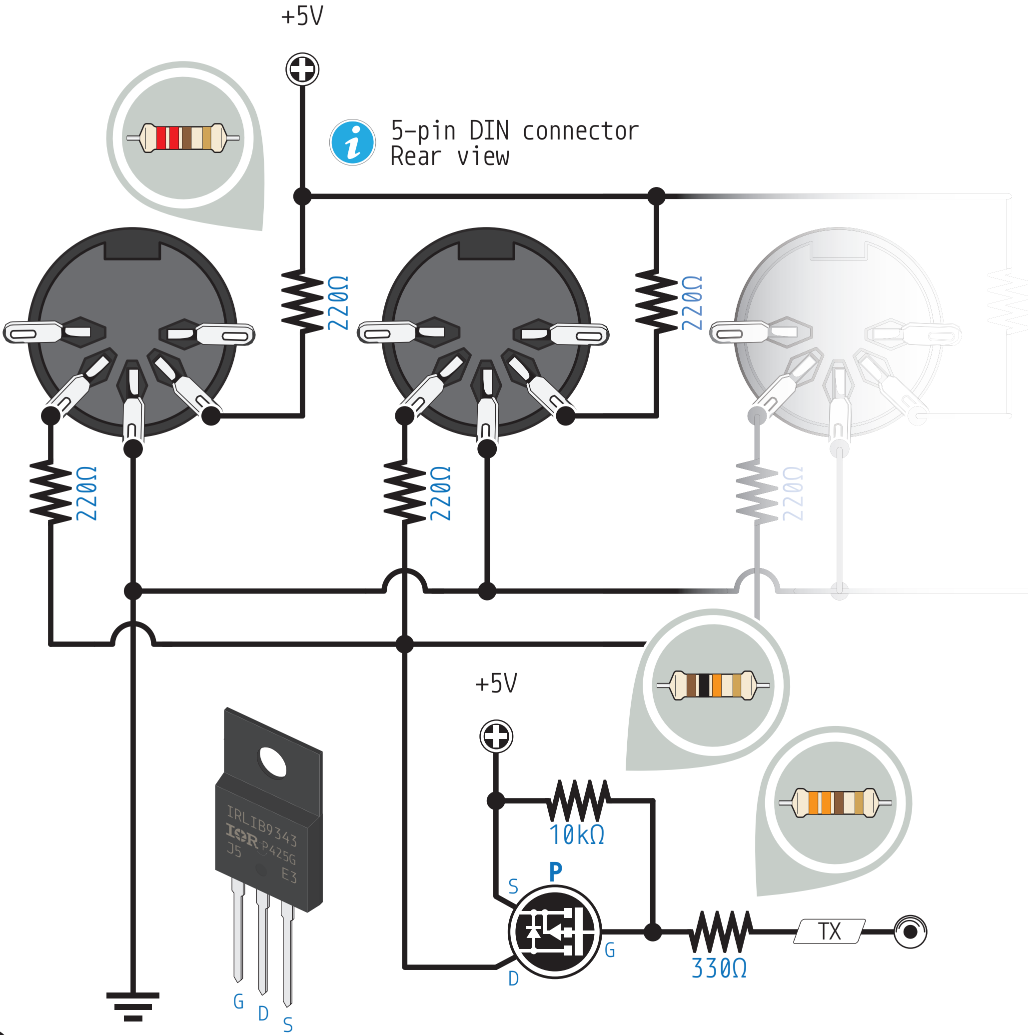
Multiple MIDI OUT

Basic Connections



IRLIB9343

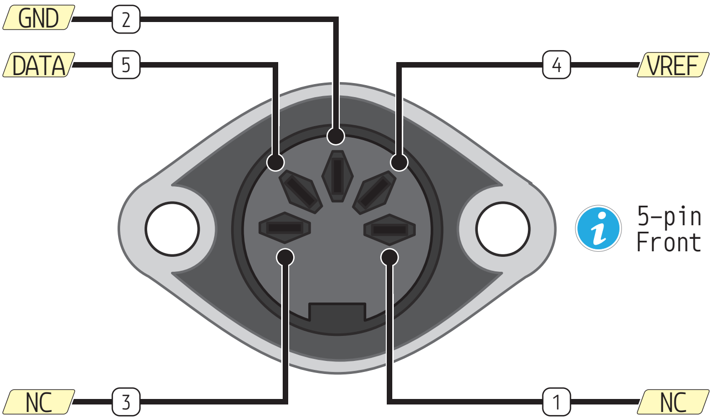
Don't forget to connect all the ground wires together!

110

0-1.es/110

MIDI

Pinout

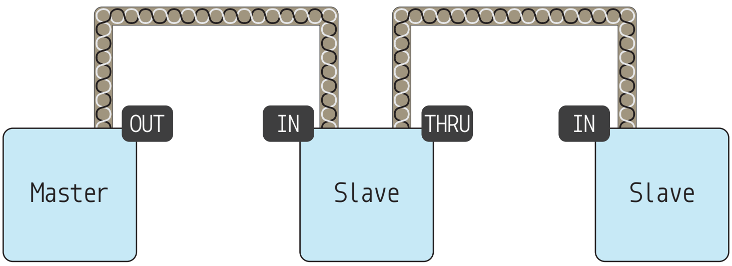


5-pin DIN connector
Front view

Pins 3 and 1 are used for implementing power over MIDI

MIDI Daisy Chain

Shielded twisted pair

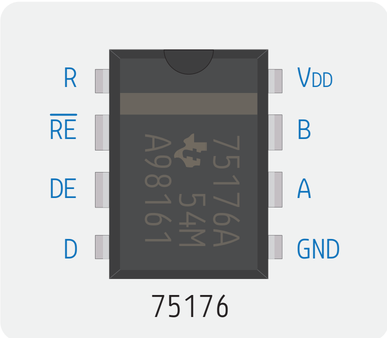


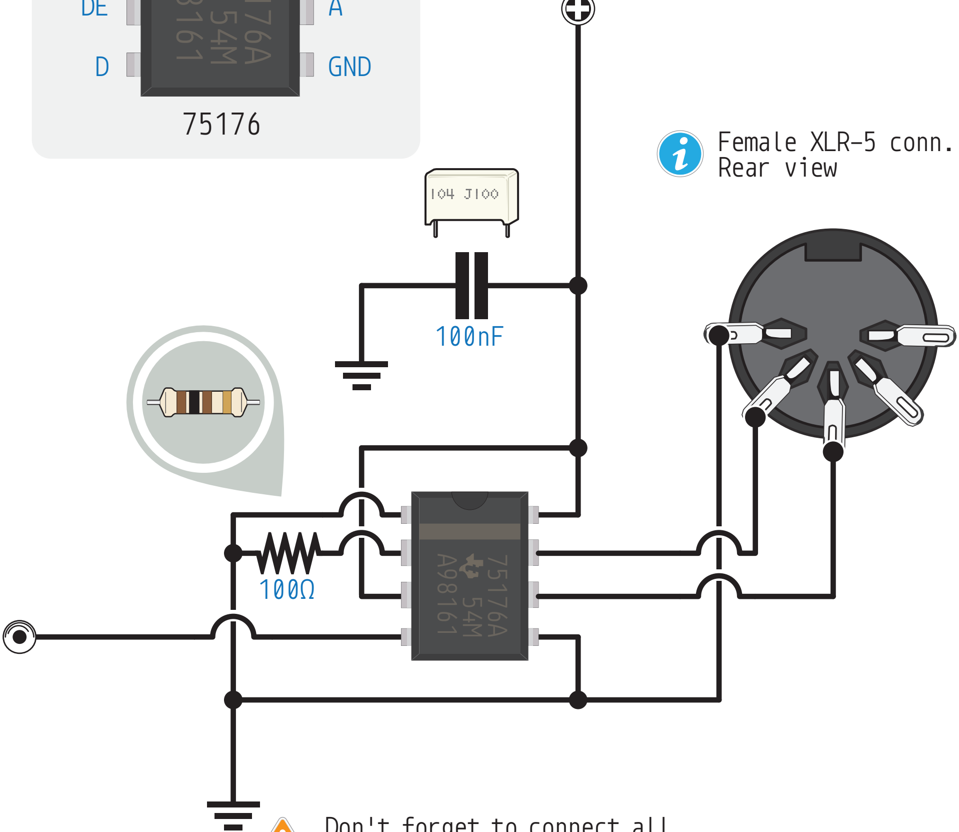
MIDI is a widely-used protocol that allows a wide variety of electronic musical instruments, computers and other related devices to connect and communicate with one another. You can build a MIDI controller with your microcontroller board and connect it to your computer to control a sequencer and play music!

0-1.es/111

DMX Interface

Using the 75176 Transceiver





Don't forget to connect all the ground wires together!

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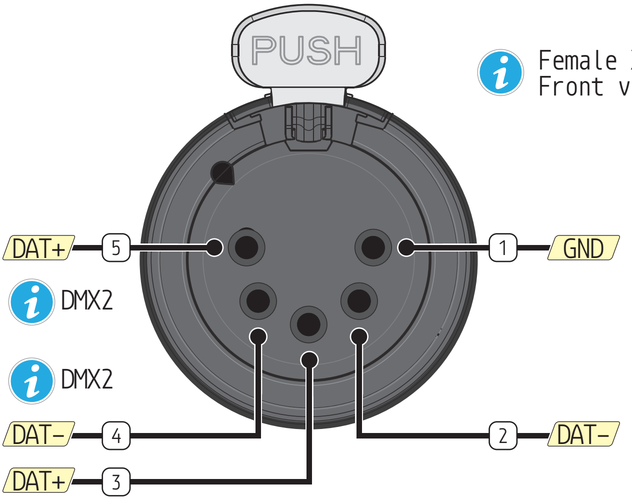
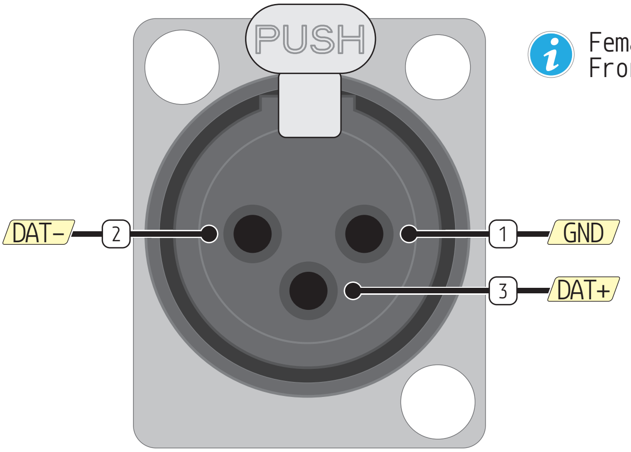
DMX
Pinout



Female XLR-5 connector
Front view



Female XLR-3 conn.
Front view

0-1.es/112

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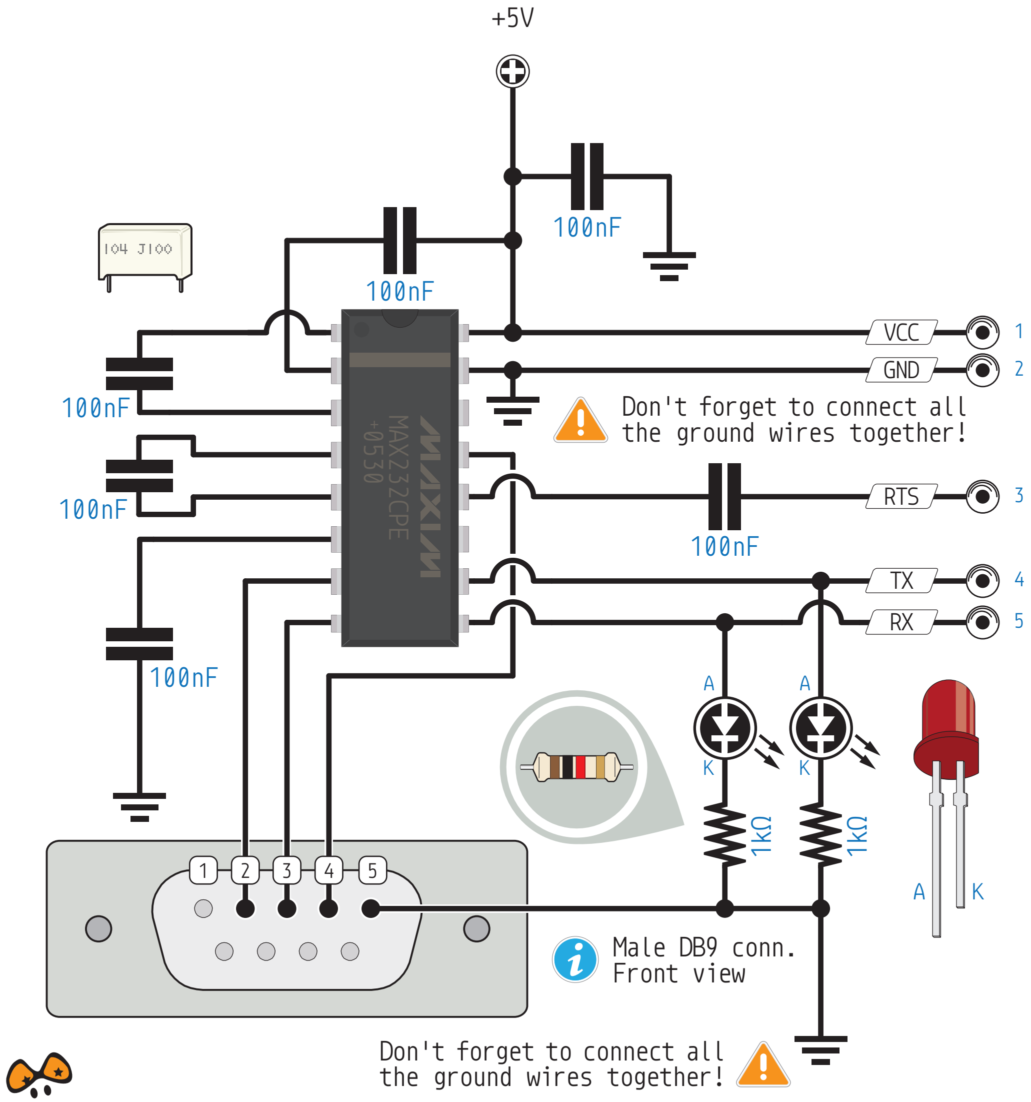
RS-232 Interface

Using the MAX232 RS-232 Driver



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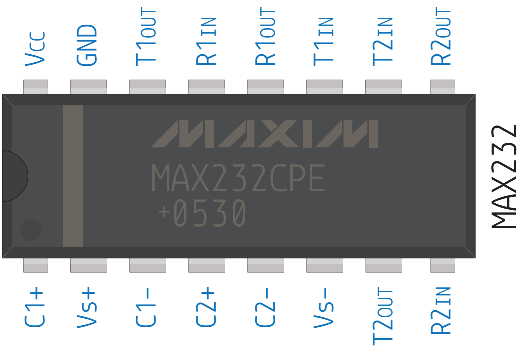
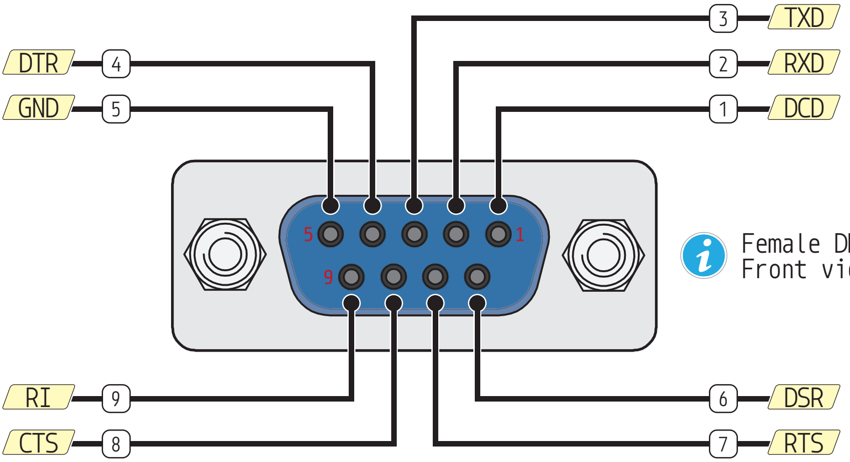
RS-232

MAX232 Pinout



RS-232 Pinout

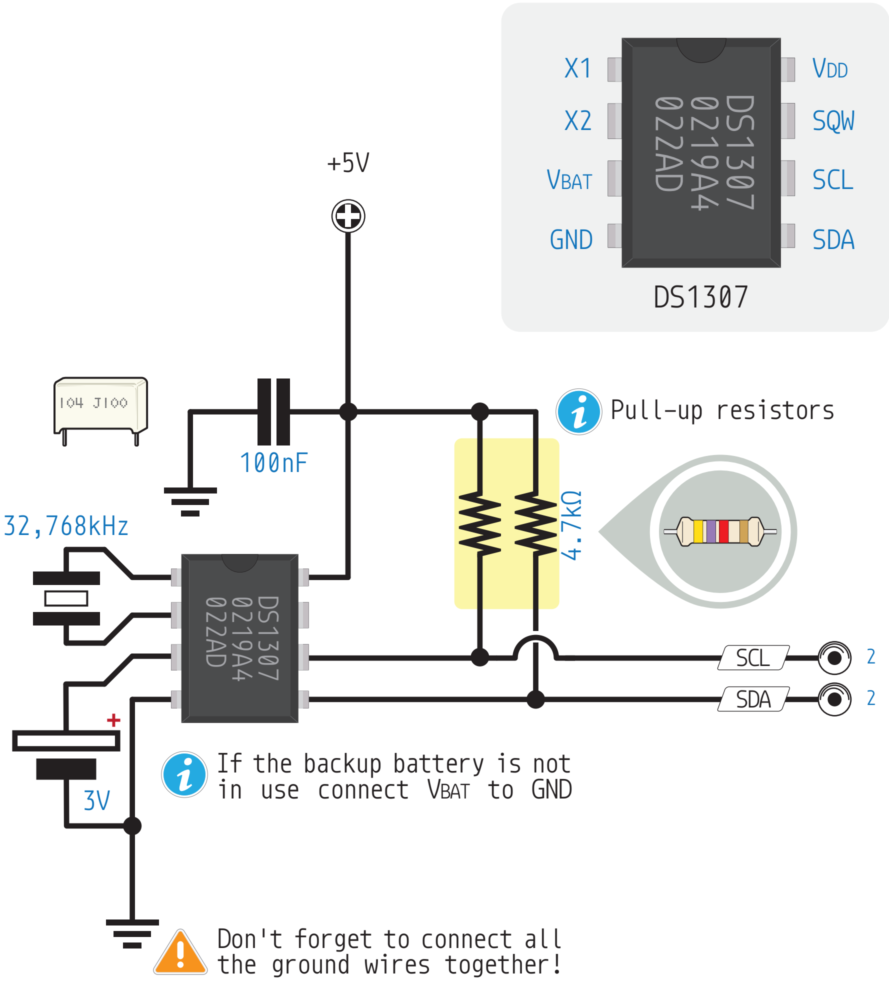


Female DB9 conn.
Front view

RS-232 is a standard for serial communication transmission of data. It was once a standard feature of a personal computer, but USB has displaced it from most of its peripheral interface roles mainly because of its low transmission speed. Nevertheless, RS-232 devices are still used, especially in industrial machines.

RTC

Using the DS1307 I²C RTC



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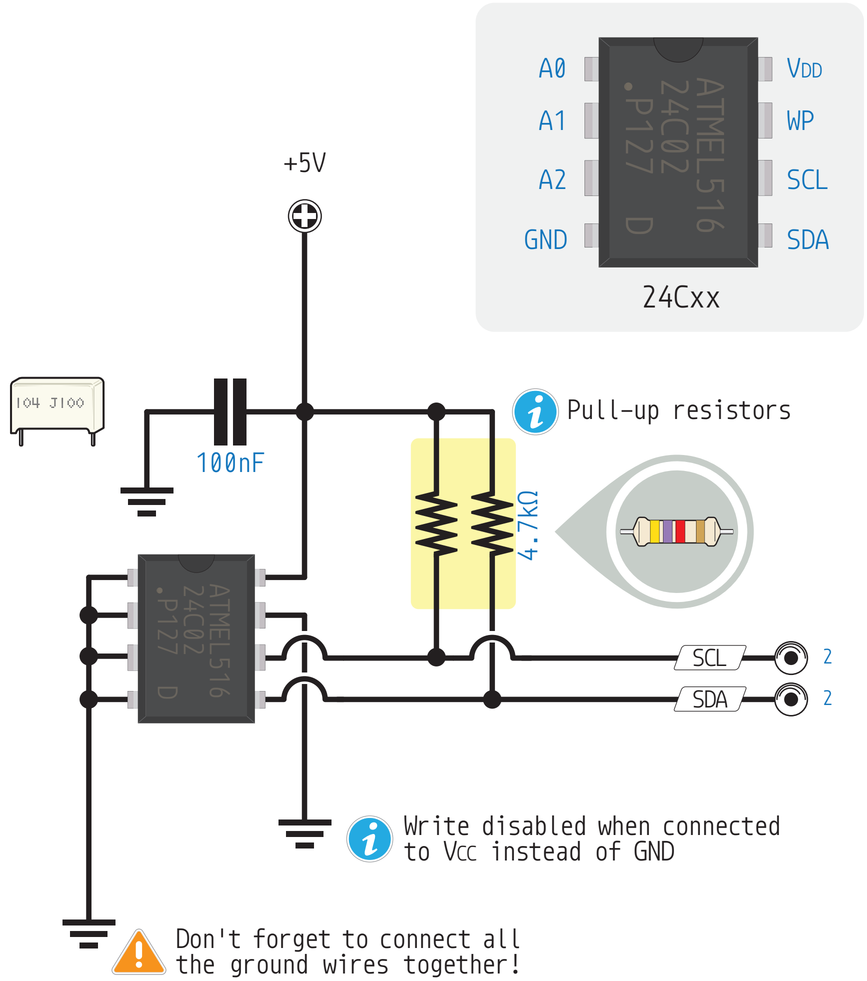
EEPROM

Using the 24Cxx Series EEPROM



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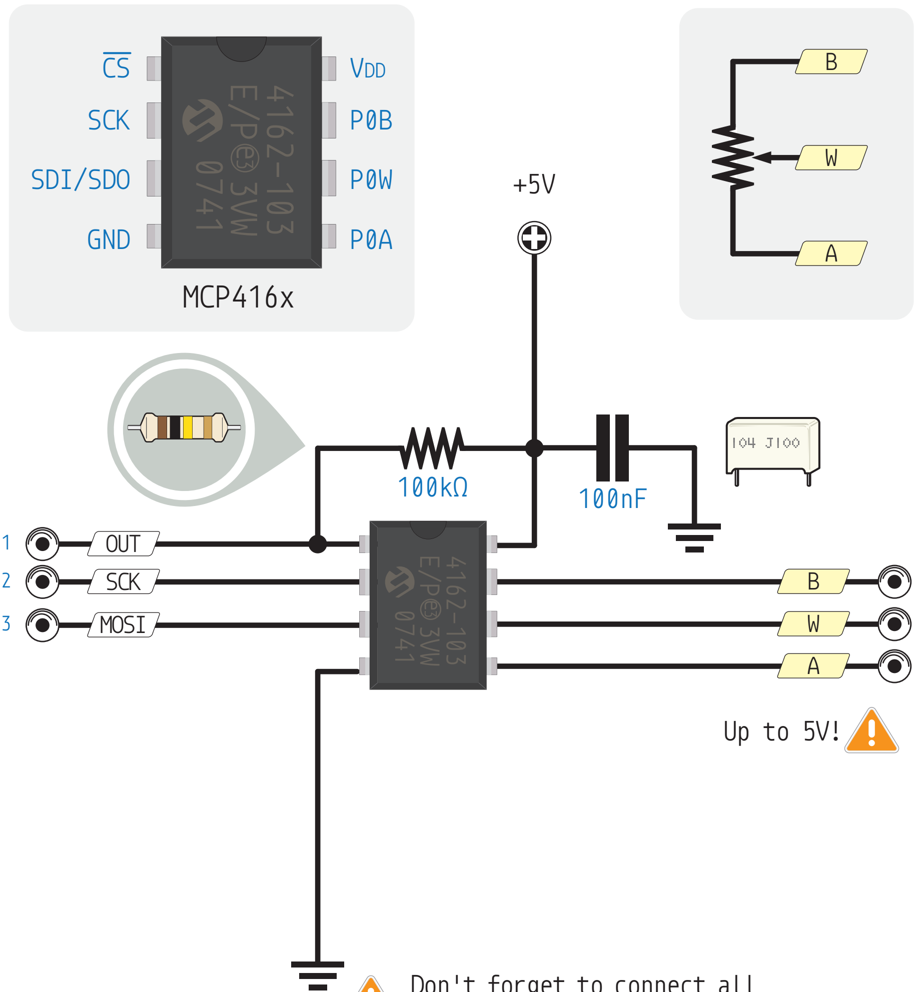
Digital Potentiometer

Using the MCP416x



Don't forget to connect all the ground wires together!

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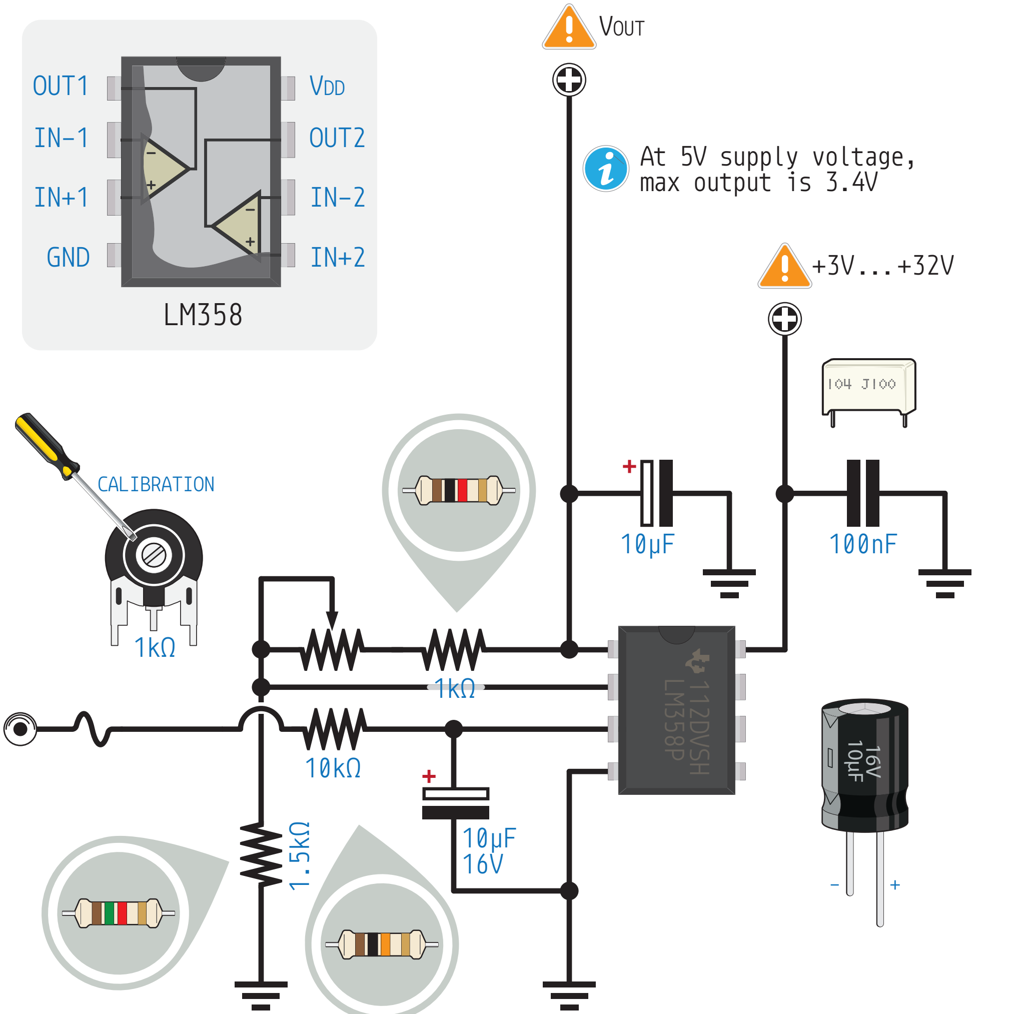
Buffer

Using the LM358



Don't forget to connect all the ground wires together!

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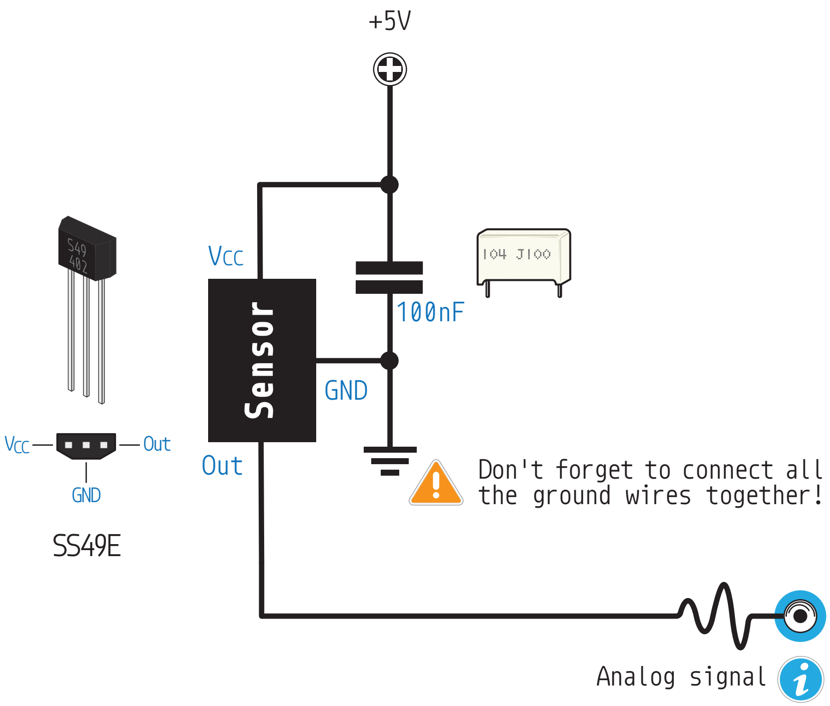
Hall Effect Sensor

Using the SS49E Hall Effect Sensor



A Hall effect sensosr are a transducesr that vary their output voltage in response to a magnetic field. The output voltage is set by the supply voltage and varies linearly in proportion to the strength of the magnetic field. They are used for proximity switching, positioning or speed detection.

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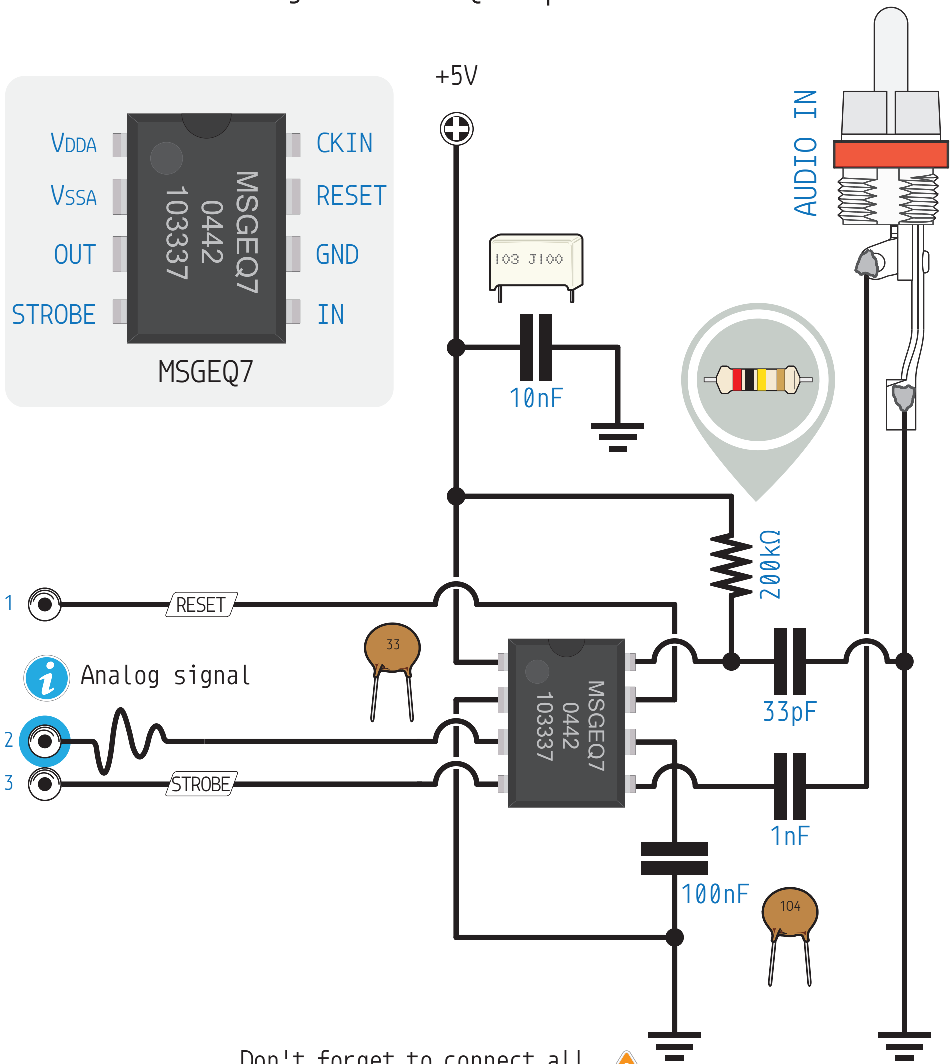
Spectrum Analyzer

Using the MSGEQ7 Equalizer



Don't forget to connect all the ground wires together!

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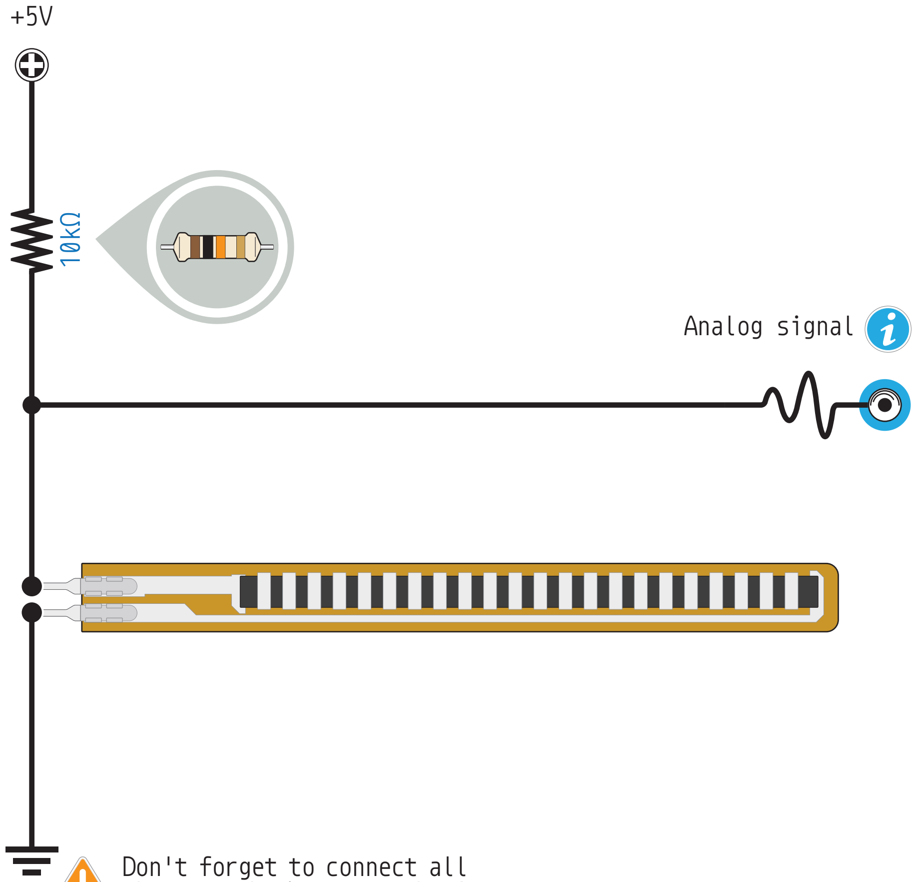
Flex Sensor

Basic Connections



Don't forget to connect all
the ground wires together!

This flex sensor is a variable resistor whose resistance increases as the body of the component bends. Sensors like these were used in the Nintendo Power Glove and are patented technology of Spectra Symbol. Please be careful not to bend them too much, especially at the base of the device, as they can get damaged.

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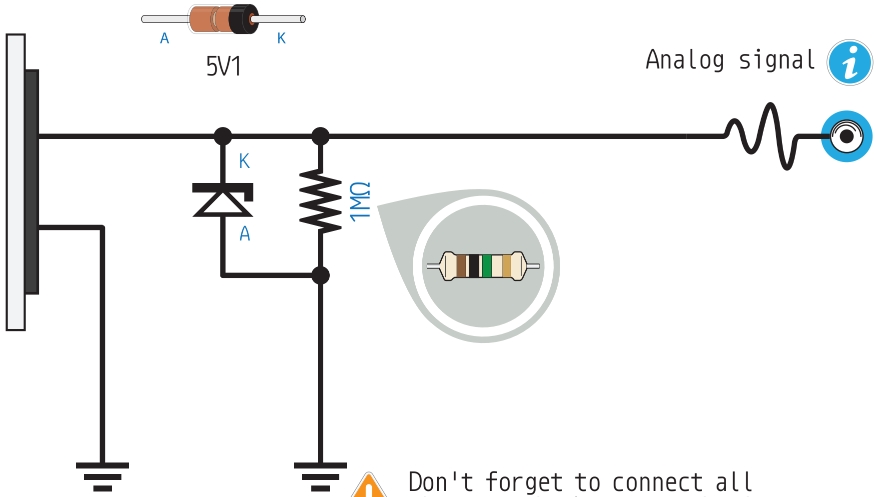
Piezo Sensor

Basic Connections



Don't forget to connect all the ground wires together!

Piezoelectric sensors use the piezoelectric effect to measure changes in pressure, vibration, temperature, strain, or force and converted into a voltage. The piezoelectric effect is generally reversible and sensors can work also as output devices. If you open a piezo buzzer you can hack it into a piezo sensor.

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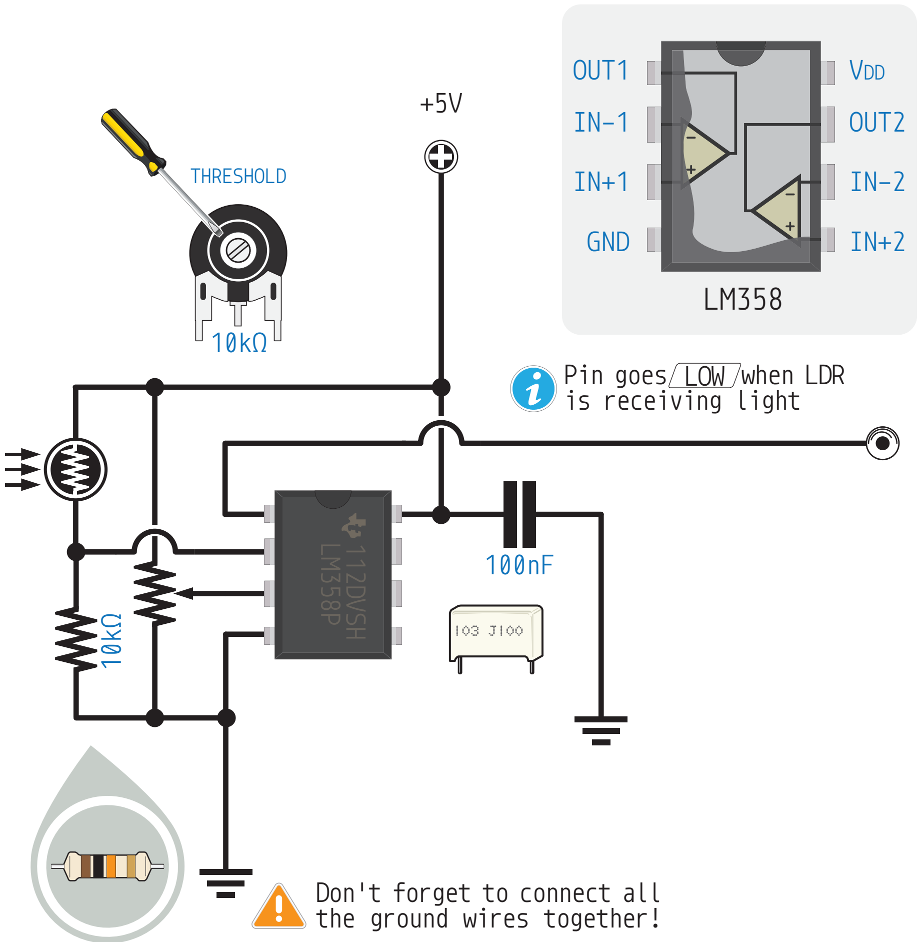
Op-Amp Threshold Switch

Using the LM358 Op-Amp



1
2
3

The LM358 op-amp acts as a voltage comparator so you have to adjust the 10kΩ potentiometer for your desired activation treshold. You could replace the photo-resistor with any other resistive sensor!

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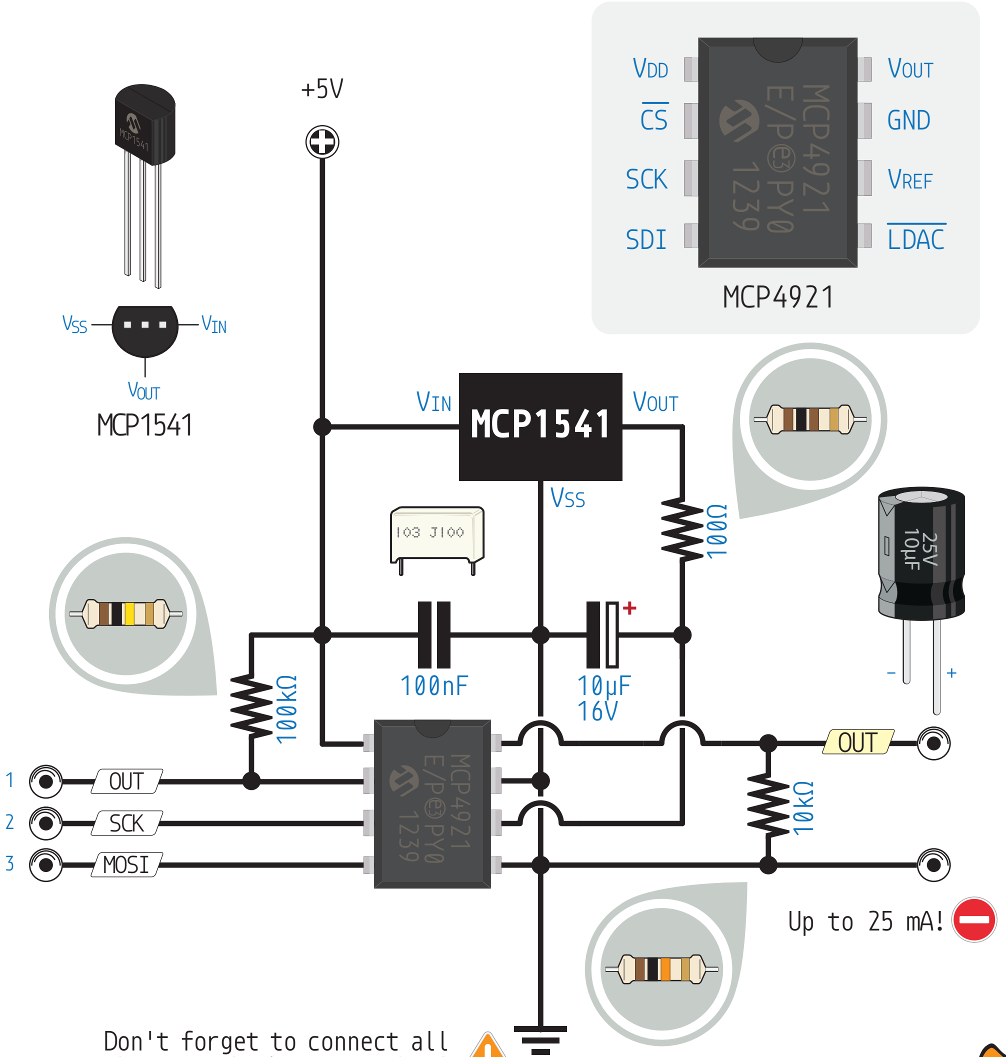
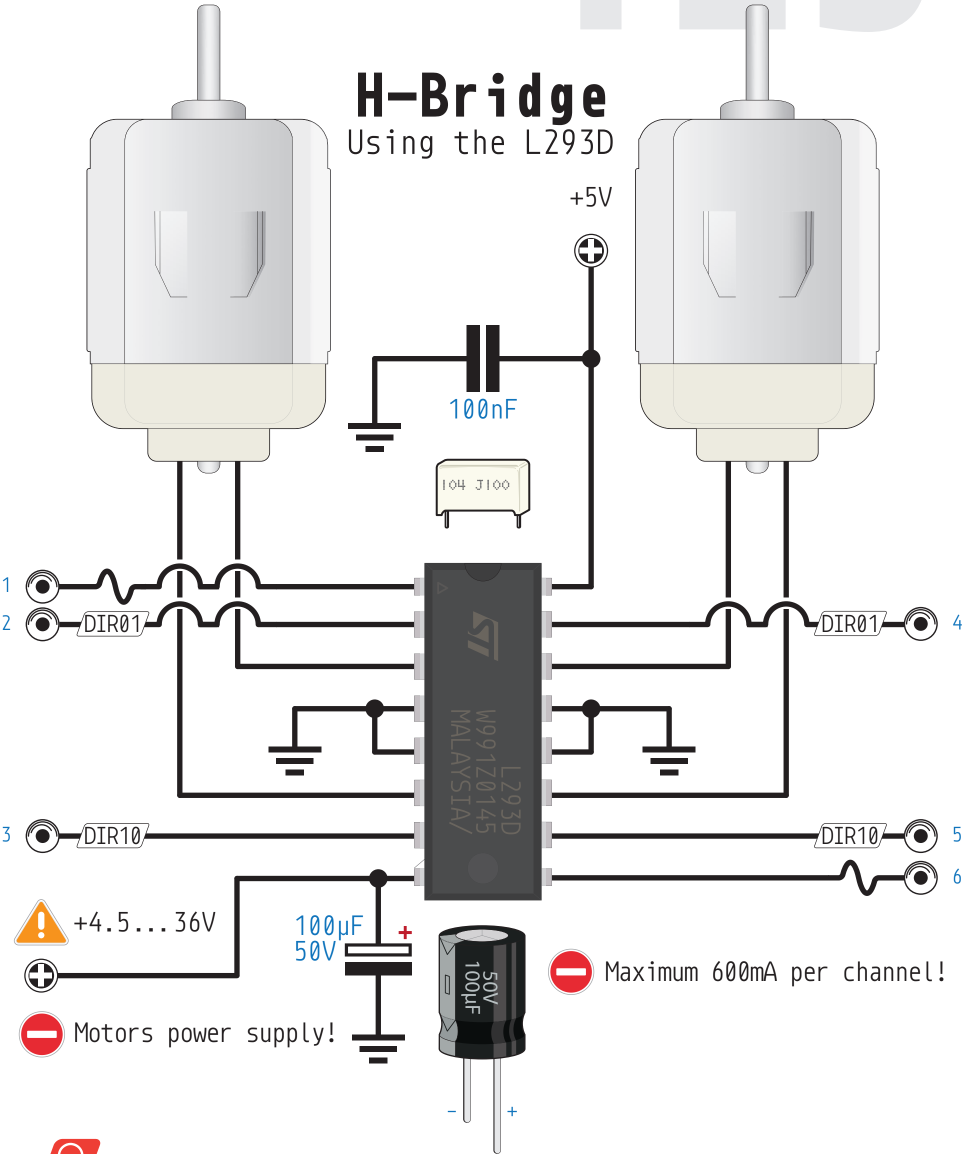
DAC

Using the MCP4921 12-Bit DAC



Don't forget to connect all the ground wires together!

H-Bridge
Using the L293D



The L293D is a quadruple high-current half-H driver. It is designed to provide bidirectional drive currents of up to 600mA at voltages from 4.5V to 36V and it is able to drive inductive loads such as relays, solenoids, DC and bipolar stepper motors.

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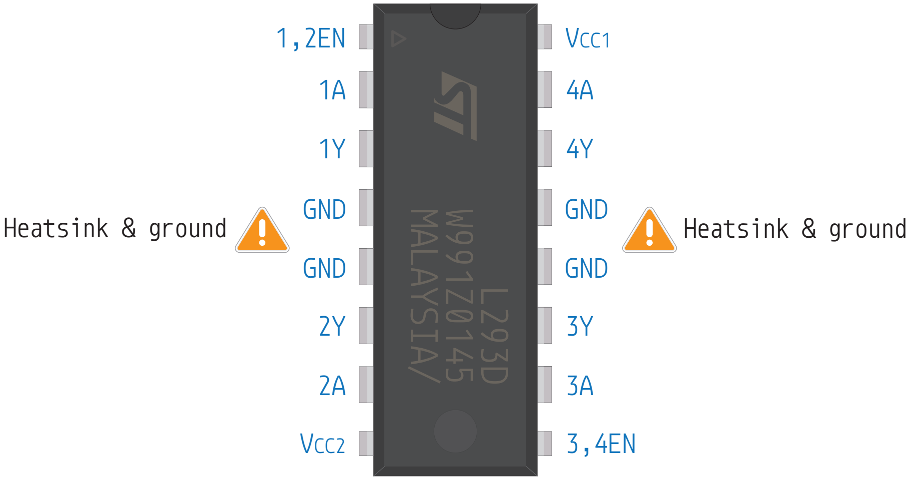
LD293D

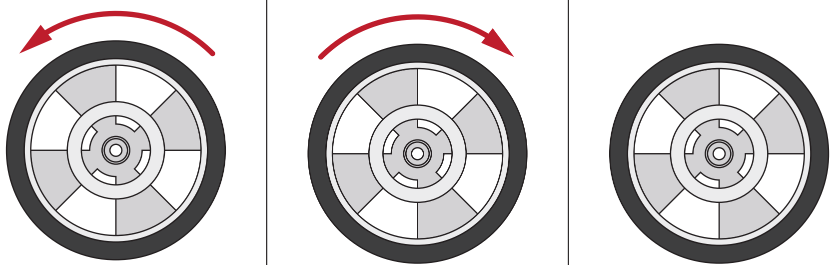
Pinout



L293D

Function Table

DIR01 DIR10 PWM Speed	DIR01 DIR10 PWM Speed	DIR01 DIR10



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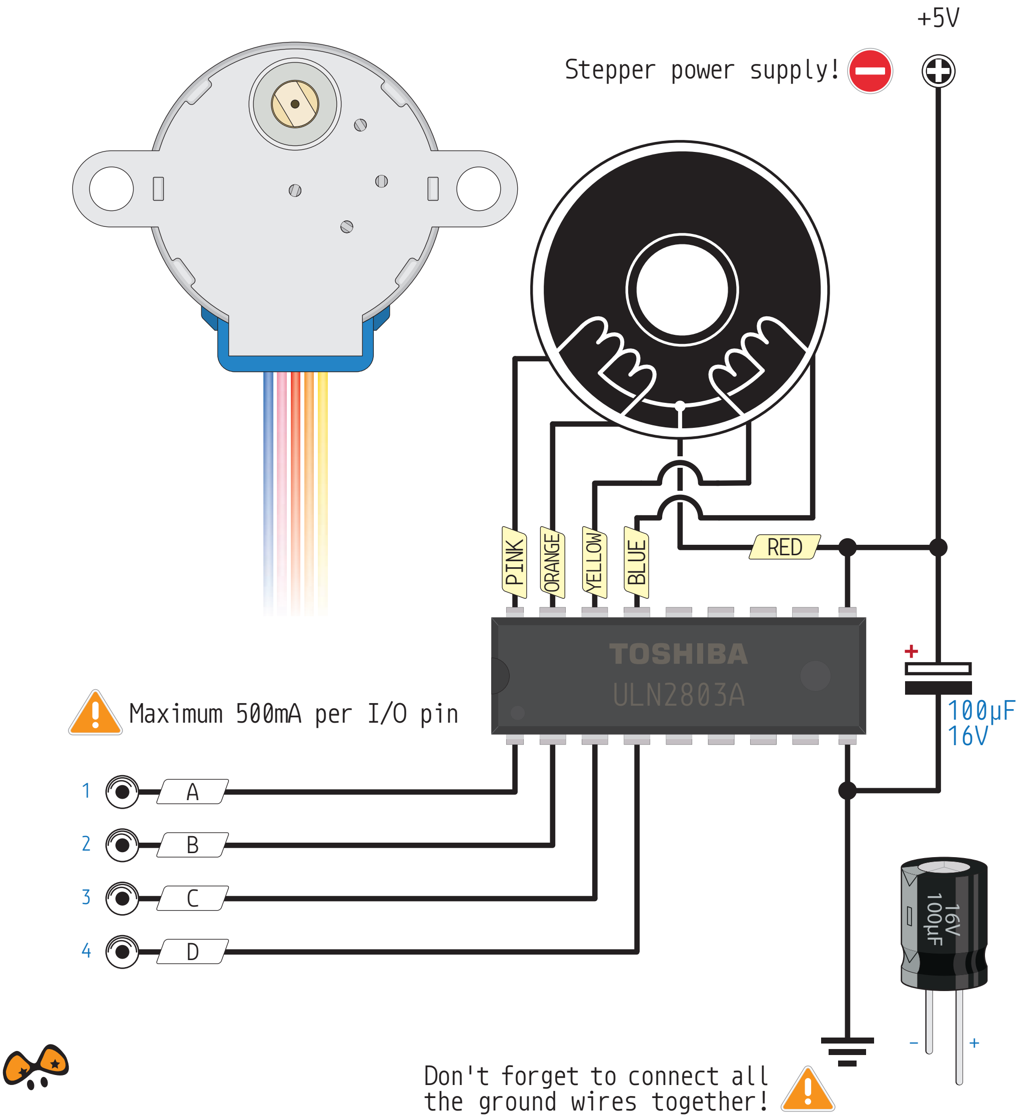
Unipolar Stepper Motor

Using the ULN2803 Darlington Transistor Array



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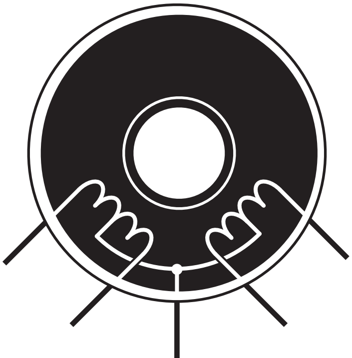
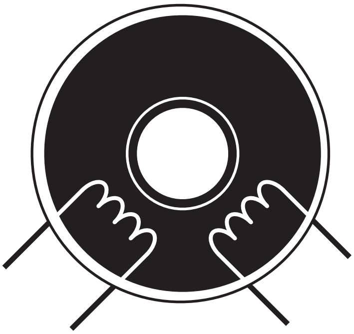
Stepper Motor

Basic Concepts

There exist two main types of stepper motors: unipolar and bipolar. In essence, they both work in the same way: electromagnets are turned on sequentially, causing the central motor shaft to turn. One difference between the two types is their voltage levels. **Unipolar** stepper motors operate only with positive voltages applied to the electromagnetic coils, e.g., 5V HIGH and 0V LOW. **Bipolar** stepper motors have two polarities: positive and negative, so their HIGH and LOW voltages would be, for instance, 2.5V and -2.5V respectively. This configuration requires H-bridge circuitry to reverse the current flow through the phases, producing the two polarities of the magnetic field. By energizing the phases with alternating the polarity, all the coils can be put to work turning the motor. Bipolar stepper motors have more torque because current flows through the entire coil, producing a stronger magnetic field to induce the shaft to rotate to the appropriate angle.



Unipolar stepper motor



Bipolar stepper motor

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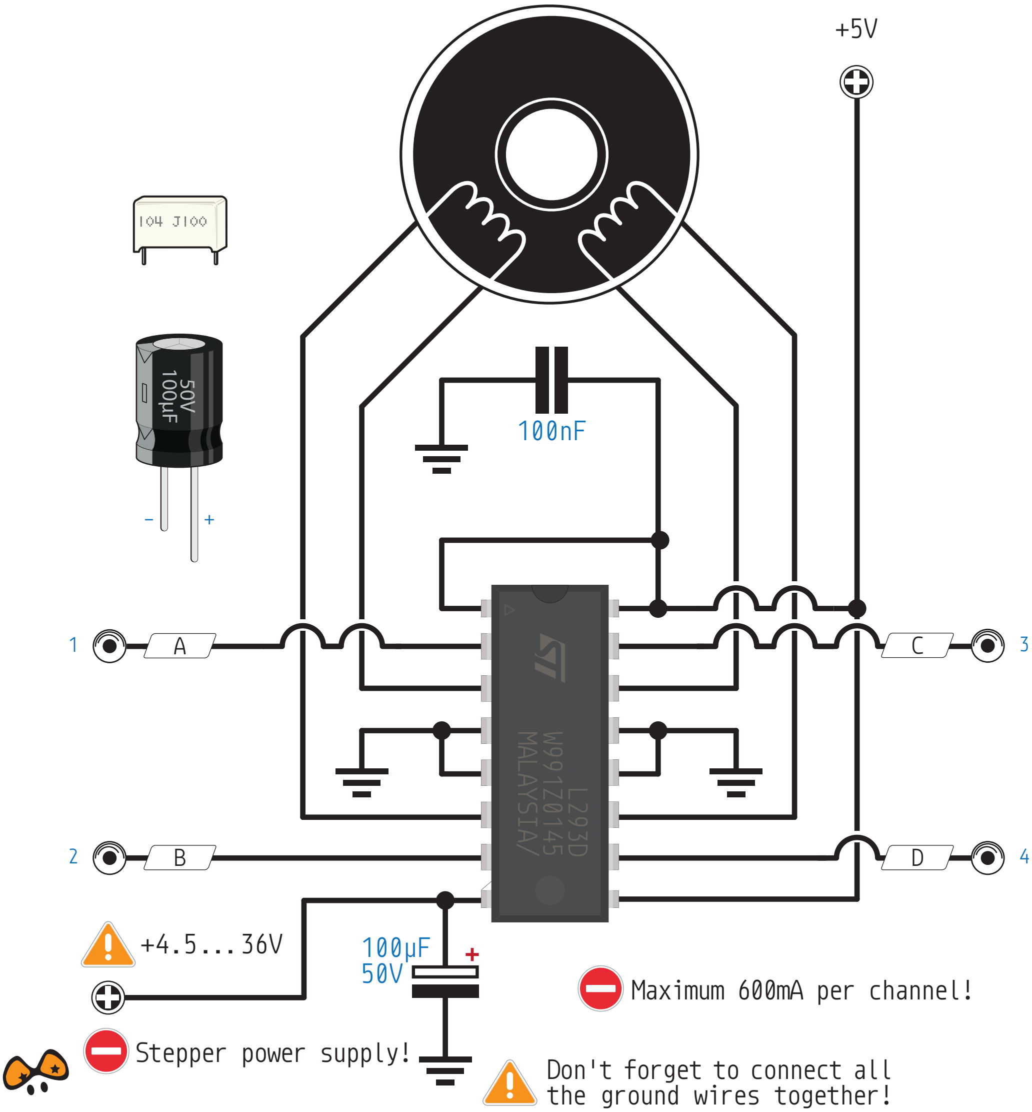
Bipolar Stepper Motor

Using the L293D Motor Driver



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Bipolar Stepper Motor

Step Sequence

Full Step				
A	B	C	D	Step
■	□	□	■	1
■	■	□	□	2
□	■	■	□	3
□	□	■	■	4

■ HIGH □ LOW

Stepper motors can be driven in two different patterns or sequences: full step sequence and half step sequence. In the full step sequence, two coils are energized at the same time and the motor shaft rotates. The order in which coils have to be energized is given in the table. In the half step sequence, the motor step angle is reduced in half, therefore the number of steps and the angular resolution are doubled. Half step mode is usually preffered over full step mode. The table shows the energizing pattern of the coils.

Half Step				
A	B	C	D	Step
■	□	□	■	1
■	□	□	□	2
■	■	□	□	3
□	■	□	□	4
□	■	■	□	5
□	□	■	□	6
□	□	■	■	7
□	□	□	■	8

■ HIGH □ LOW

Step Angle

The step angle of a stepper motor is defined as the angle traversed by the stepper motor in one step. To calculate step angle simply divide 360 by the number of steps that it takes the stepper motor to complete one revolution. In half step mode, the number of steps per revolution doubles.

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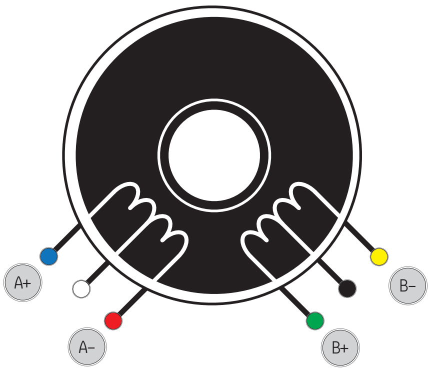
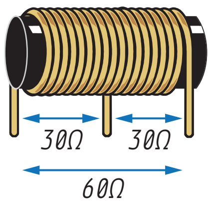
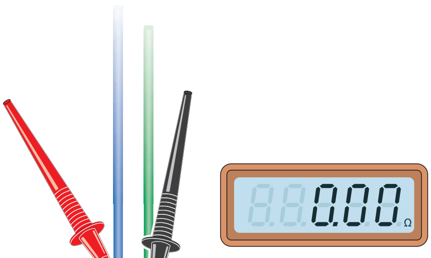
Stepper Motor
Phases

It's easy to identify which color corresponds to each phase inside the stepper motor, as well as the common terminals (A and B). We assume that each coil has a resistance of 30Ω.

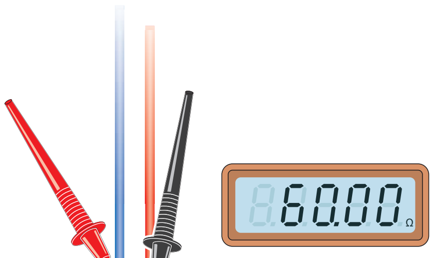




Use a multimeter and set it to the 200Ω range. Place the positive (+) terminal of the tester on a wire (e.g., blue) and with the negative terminal of the tester (–) begin measuring the resistance on all remaining wires.



Blue–Green



Blue–Red

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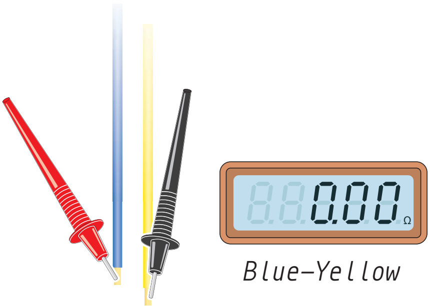
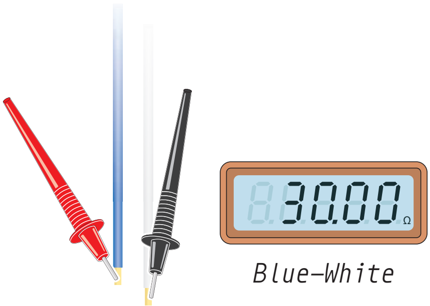
Stepper Motor

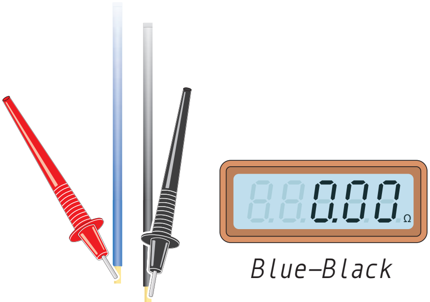
Phases



Blue-Yellow



Blue-White



Blue-Black

Measuring the resistance with the rest of wire combinations, we will obtain a table with all measured values:

	Blue	Green	Red	Yellow	White	Black
Blue		∞	60Ω	∞	30Ω	∞
Green	∞		∞	60Ω	∞	30Ω
Red	60Ω	∞		∞	30Ω	∞
Yellow	∞	60Ω	∞		∞	30Ω
White	30Ω	∞	30Ω	∞		∞
Black	∞	30Ω	∞	30Ω	∞	

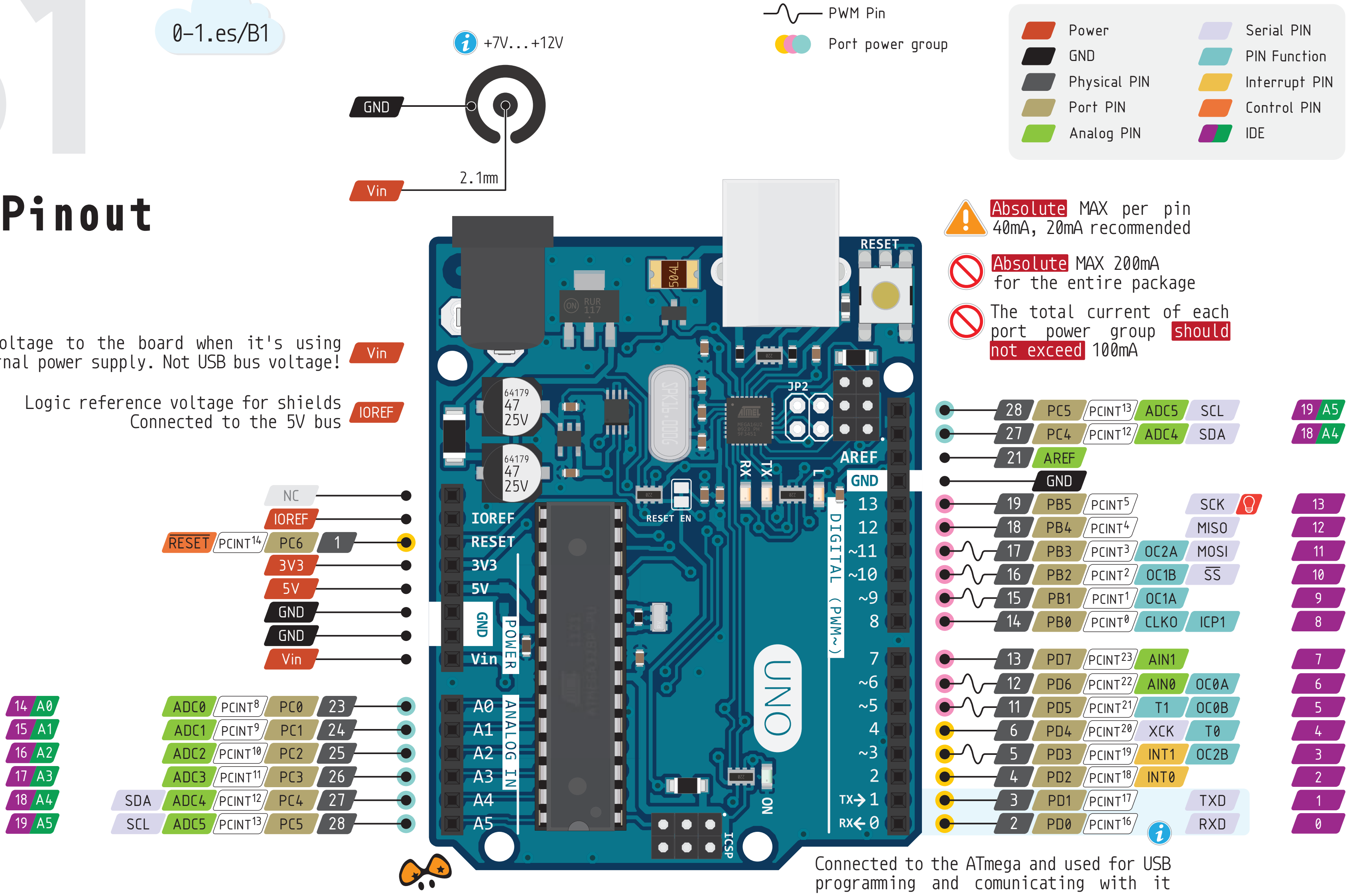
From these measurements it can be deduced that the connections are of this type:

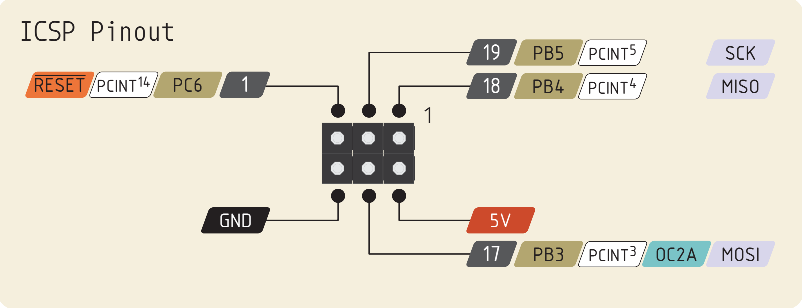
Blue	Green	Red	Yellow	White	Black
A+	B+	A-	B-	A	B

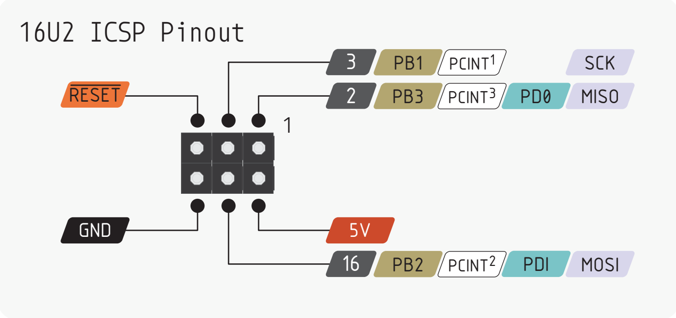
B1

UNO Pinout

0-1.es/B1

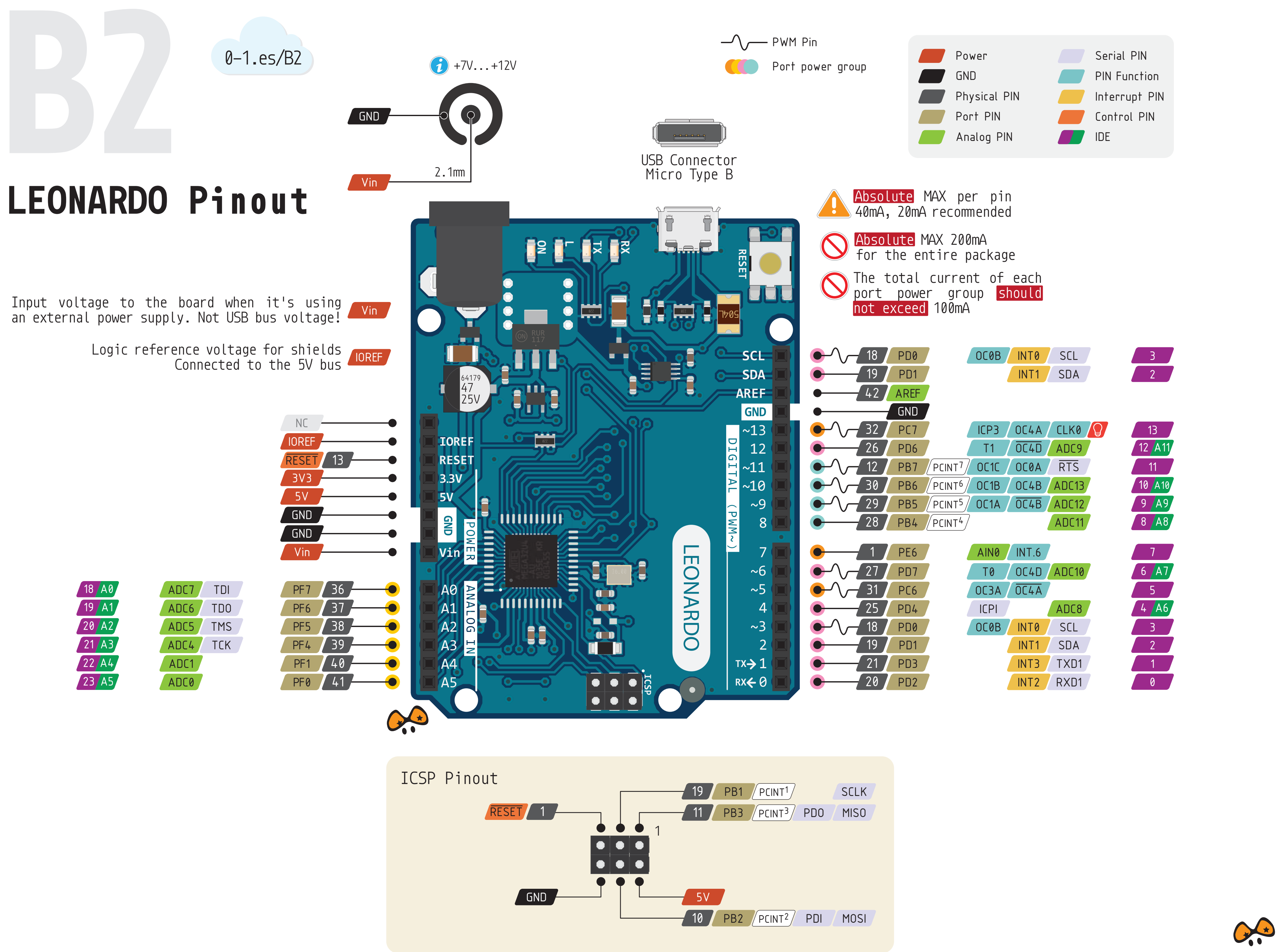






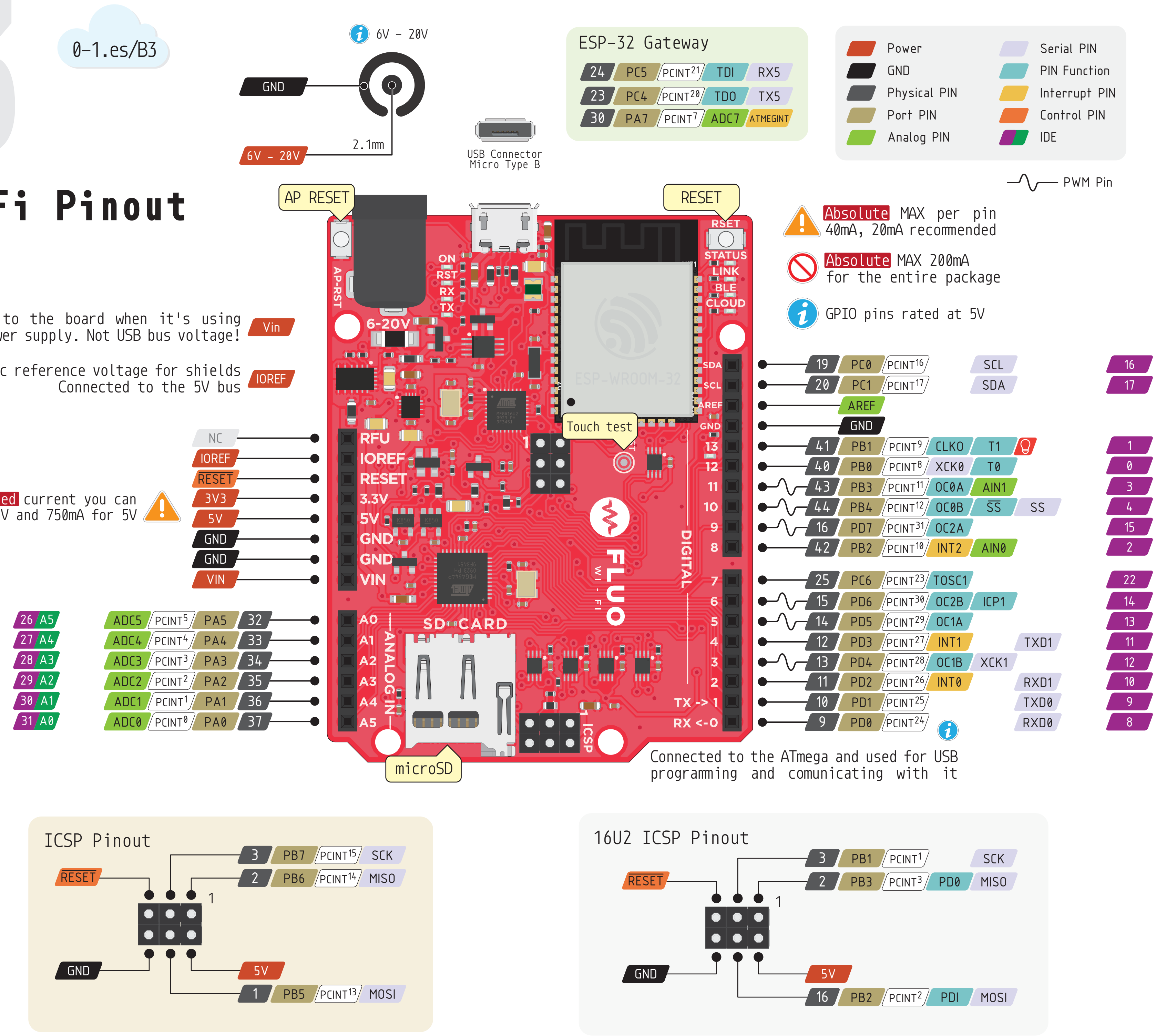
B2

LEONARDO Pinout



B3

FLUO WiFi Pinout



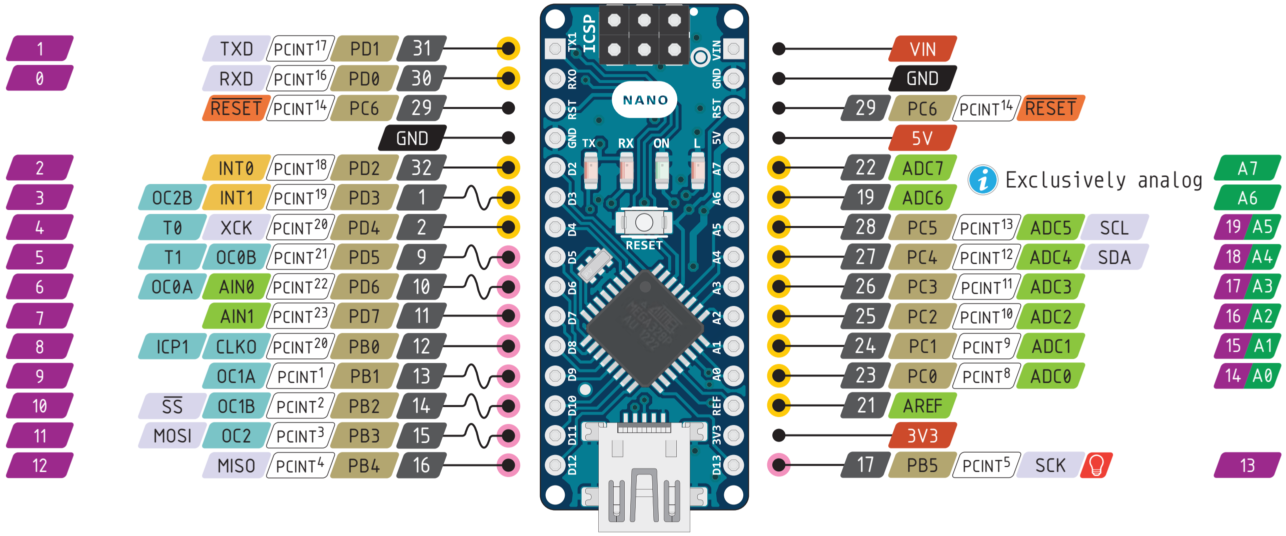
B4

0-1.es/B4

Nano Pinout

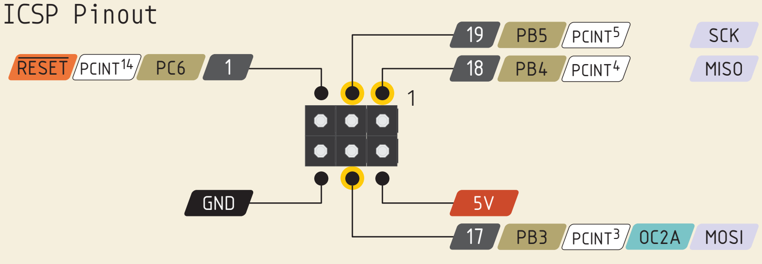
PWM Pin
Port power group

Power
GND
Physical PIN
Port PIN
Analog PIN
Serial PIN
PIN Function
Interrupt PIN
Control PIN
IDE



USB Connector
Mini Type B

ICSP Pinout



VIN Input voltage to the board when it's using an external power supply. Not USB bus voltage!

Absolute MAX per pin 40mA, 20mA recommended

Absolute MAX 200mA for the entire package

The total current of each port power group should not exceed 100mA

B5

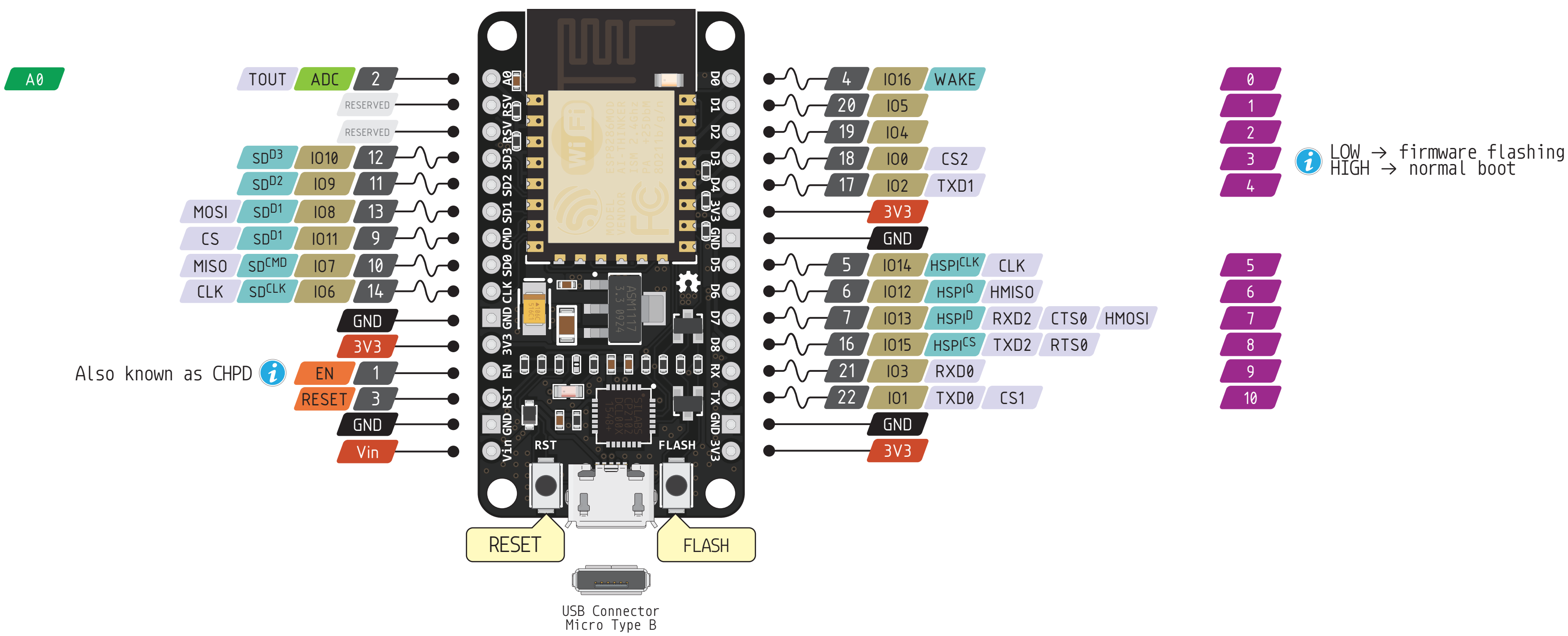
0-1.es/B5

NodeMCU Pinout

Power
GND
Physical PIN
Port PIN
Analog PIN
Serial PIN
PIN Function
Interrupt PIN
Control PIN

PWM Pin

Vin USB bus voltage



B6

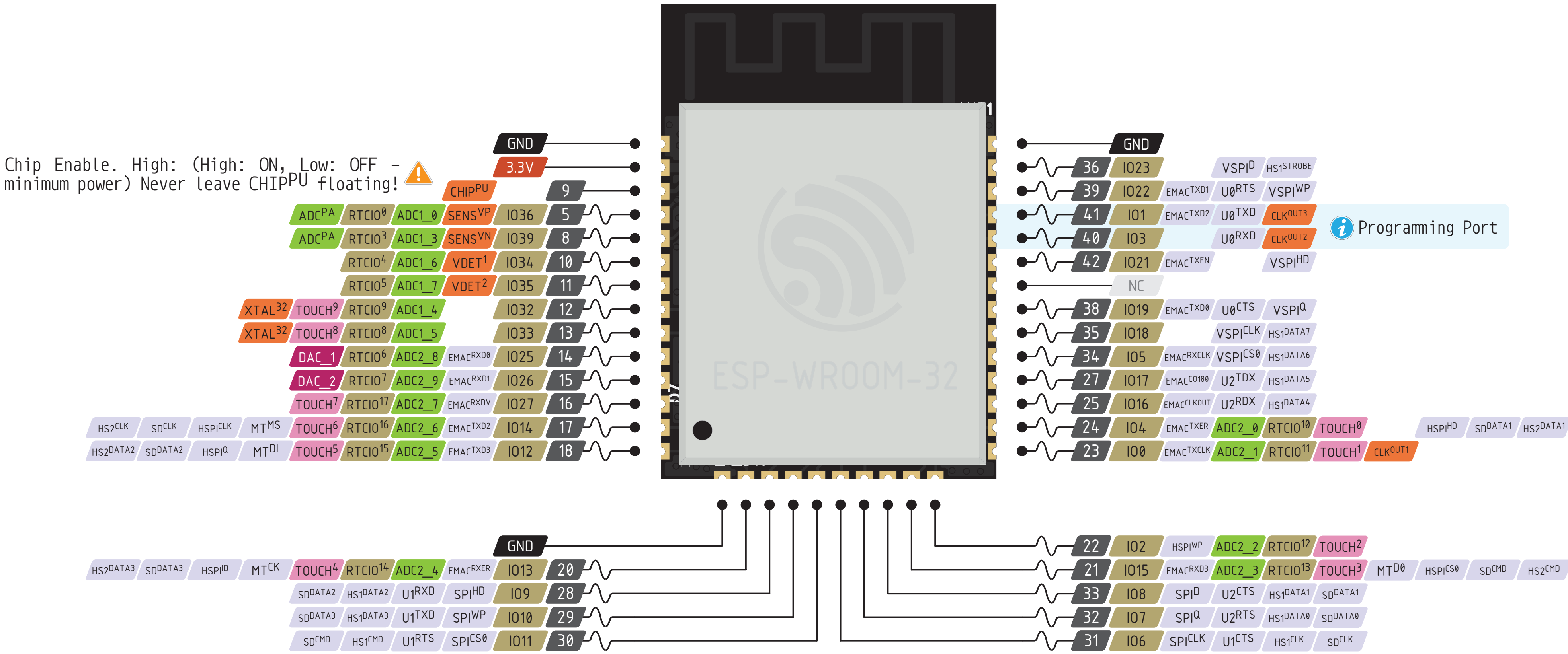
0-1.es/B6

ESP-WROOM-32 Pinout

Power
GND
Physical PIN
Port PIN
Analog PIN
Touch Pin
Serial PIN
PIN Function
Interrupt PIN
Control PIN
IDE
DAC Pin

PWM Pin

Absolute MAX per pin
12mA, 6mA recommended

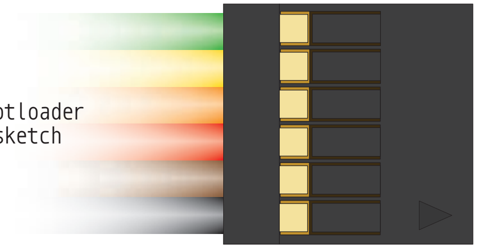


B7

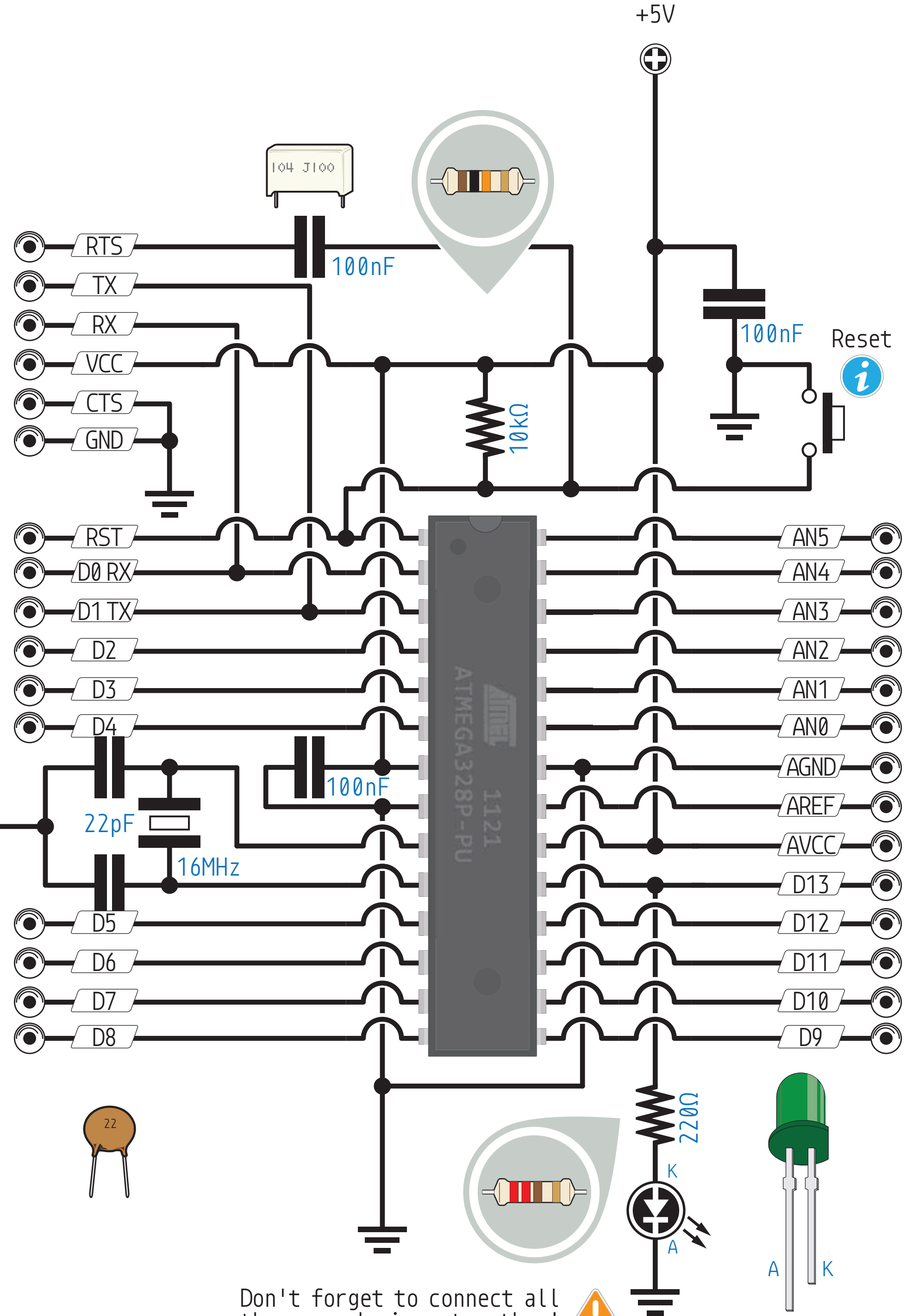
0-1.es/B7

DIY Microcontroller Board

Basic Connections



Use the ICSP port to burn the bootloader
Use the FTDI port to upload the sketch

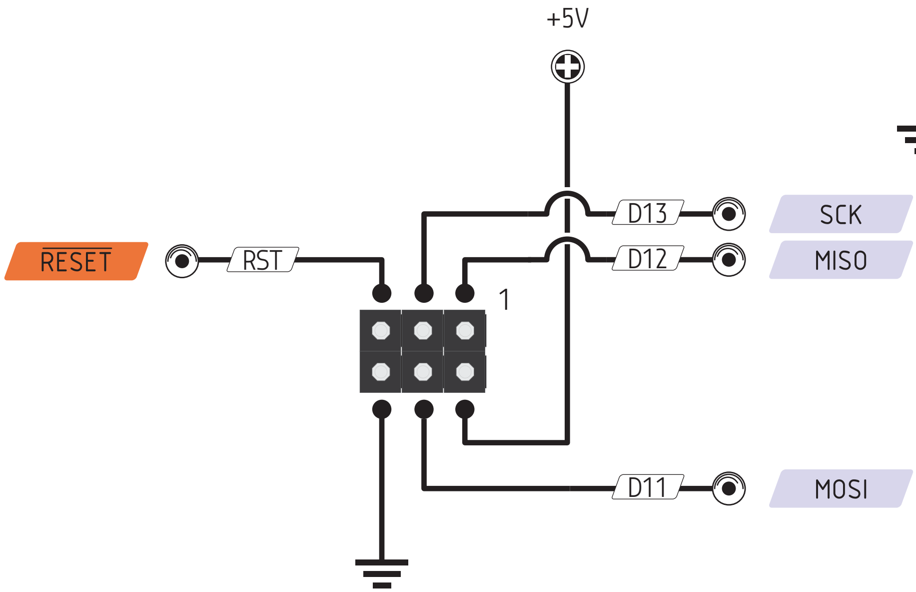


Absolute MAX per pin 40mA, 20mA recommended

Absolute MAX per pin 200mA for the entire package

The total current of each port power group should not exceed 100mA

ICSP Connections



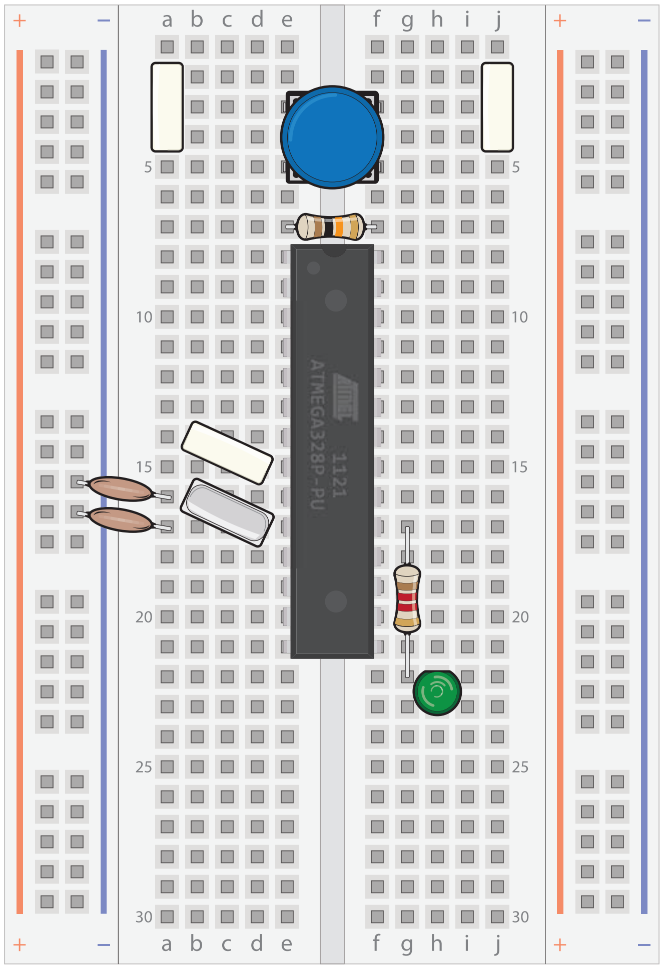
Don't forget to connect all the ground wires together!

B7

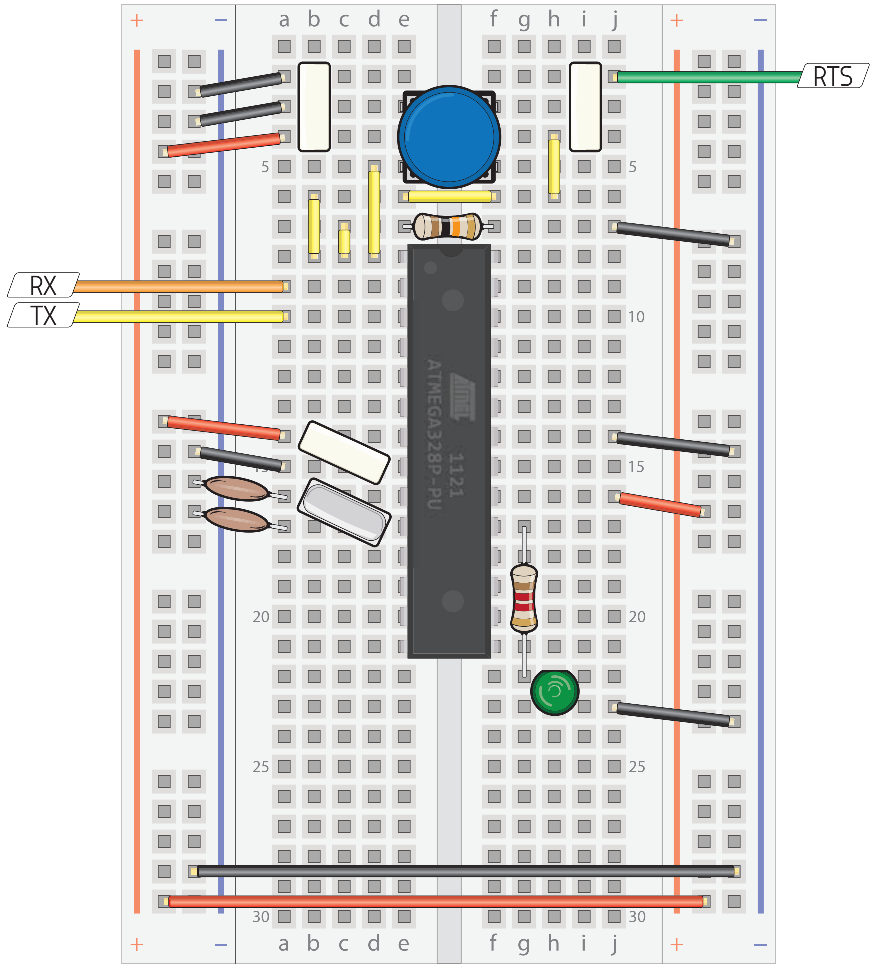
0-1.es/B7

DIY Microcontroller Board

Breadboard



Step 1 of 2



Step 2 of 2

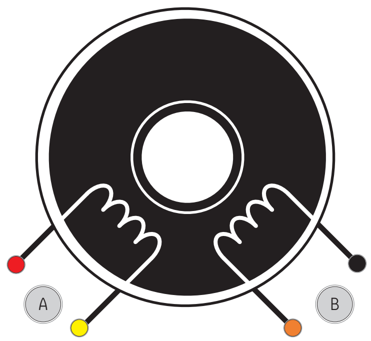
B8

0-1.es/B8

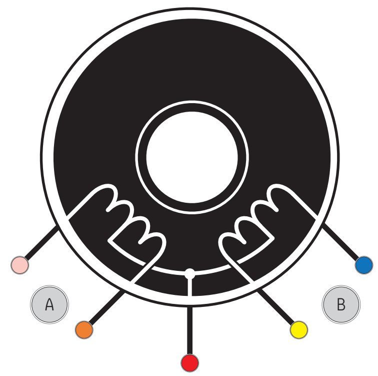
Stepper Motor
Winding Configurations

Not all manufacturers use the color schemes represented here, please check the datasheet

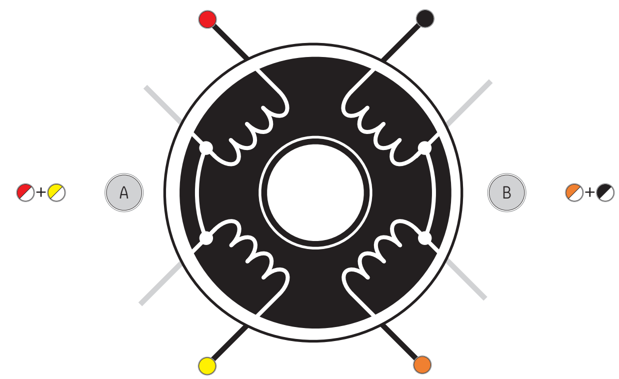
4-Lead Bipolar



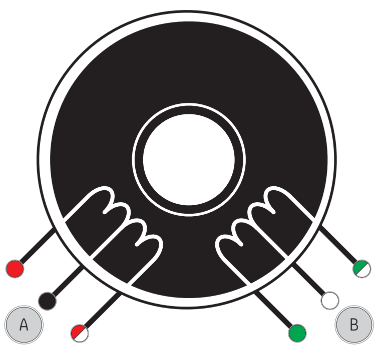
5-Lead Unipolar



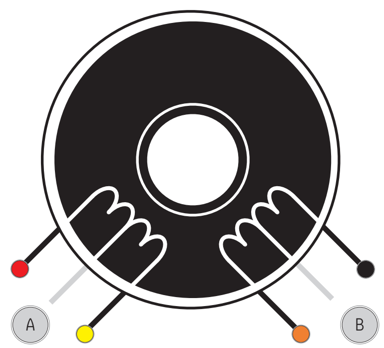
8-Lead Bipolar (Series)



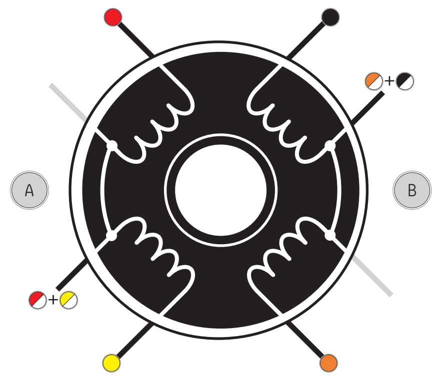
6-Lead Unipolar



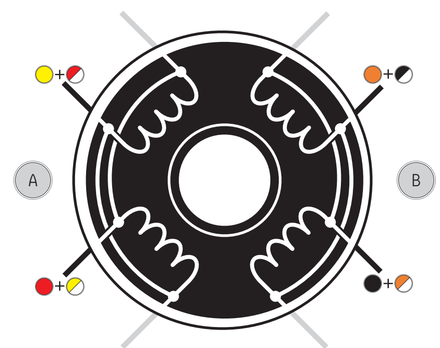
6-Lead Bipolar (Series)



8-Lead Unipolar



8-Lead Bipolar (Parallel)



B9

0-1.es/B9

L298N Motor Driver

Basic Connections